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ELF Communications System Ecological Monitoring Program: Summary of 1989 Progress

John E. Zapotosky

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A long-term ecological monitoring program is being conducted to monitor for possible electromagnetic effects that operation of the U.S. Navy's ELF Communications System might have on resident biota and their ecological relationships. Monitoring studies were selected through a peer-reviewed, competitive bidding process in mid-1982, and work on most studies began in late summer of that year. Preliminary activities of the program consisted of site selection, characterization of critical study aspects, and validation of assumptions made in original proposals. Data collection for studies at the Naval Radio Transmitting Facility (NRTF)-Clam Lake, Wisconsin, was completed, as scheduled, during 1989. Data collection for studies at the NRTF-Republic, Michigan, is planned to continue through 1991. This report summarizes the progress of the monitoring program during 1989.

To date, investigators conclude that no effects have occurred on biota exposed to EM Fields produced by either a fully operational or an intermittently energized ELF transmitting facility.

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FOREWORD

The U.S. Department of the Navy is conducting a long-term program to monitor for possible effects that operation of the Navy's Extremely Low Frequency (ELF) Communications System might have on resident biota or their ecological relationships. The program is funded by the Space and Naval Warfare Systems Command through a contract to IIT Research Institute (IITRI). IITRI provides engineering support to the program and coordinates the efforts of ecological study teams. Monitoring projects are being conducted under subcontract arrangements between IITRI and university investigators.

This report summarizes the activities of the ELF Communications System Ecological Monitoring Program during 1989. The information presented was derived from other, more detailed technical reports of ecological findings and electromagnetic exposures.[1,2]

Since the inception of the program in 1982, IITRI has annually compiled subcontractor reports of efforts and findings,[3-9] documented engineering support activities,[10-15] and summarized the progress of the program.[16-22] Subcontractor reports have been peer reviewed, and all were submitted (unedited by the Navy or IITRI) to the National Technical Information Service for unlimited distribution. Investigators have also related their findings as presentations to scientific societies and as articles in peer-reviewed journals. Appendix A lists the presentations and publications.

Respectfully submitted,

IIT RESEARCH INSTITUTE

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GLOSSARY AND ACRONYMS

AIBS	American Institute of Biological Sciences.
ANOVA	Analysis of Variance, a statistical technique for partitioning the total variability affecting a set of observations between the possible and statistically independent causes of the variability.
ANCOVA	Analysis of Covariance, a statistical method for determining whether the functional relationships described by two or more regression equations are the same; it is used when treatments are compared in the presence of accompanying variables that cannot be eliminated or regulated.
ATP	adenosine triphosphate.
BACI	Before and After, Control and Impact, a statistical technique which compares the mean of the "before" differences between the control and impact (treatment) sites to the mean of the "after" differences between sites by using an unpaired t-test; also known as intervention analysis.
biomass	quantitative estimate of the total mass of living organisms comprising all or part of a specified unit such as a population.
chi-square test	a statistical method for testing the degree to which observed frequencies or values differ from frequencies or values expected from the specific hypothesis being tested.
clone	an assemblage of genetically identical organisms derived by a sexual or vegetative multiplication from a single sexually derived individual.
clutch	the number of eggs laid at any one time.
control site	a location where parallel observations or experiments are carried out; they provide a standard against which a result can be compared. As used in this report, it is a location remote from the ELF Communications System, having 76 or 44 Hz EM intensities at least one order of magnitude less than its matched treatment site.
dendrometer bands	a method of measuring plant growth by examining increases in trunk or stem diameter.
detritivore	an animal feeding on fragmented particulate organic matter.
diel	pertaining to a 24-hour period.
edge effect	the impact exerted by adjoining communities on the population structure within the marginal zone which often contains a greater number of species and higher population density of some species than either adjoining community.
ELF	Extremely Low Frequency, in general use, refers to frequencies ranging from 0 to 300 Hz; as used in this report, refers to operating frequencies of Navy's ELF Communications System (i.e., 76 ±4 Hz, 44 ±4 Hz).

EM	Electromagnetic.
evapotranspiration	the loss of water of water by evaporation from soil and transpiration from vegetation.
evenness	the apportionment of individuals among those species found in a given community.
fecundity	the potential reproductive capacity of an organism or population, measured by the number of gametes.
generation time	the average duration of a life cycle between birth and reproduction.
genetic diversity	a measure of the genotypic disparity within a population, the different forms of a gene occupying the same locus or loci.
guild	a group of species having similar ecological resource requirements and foraging strategies, and therefore having similar roles in the community.
herbaceous plants	plants which have stems that are not secondarily thickened or lignified and which die down annually.
litter	recently fallen plant material which is only partially decomposed and in which the organs of the plant are still discernible, forming the surface layer on some soils.
MDD	Minimum Detectable Difference, magnitude of the smallest change that can be perceived for a given sample size and parameter variance.
MSU	Michigan State University.
MTU	Michigan Technological University.
mycelium	mass of filamentous hyphae that comprises the vegetative stage of many fungi.
mycorrhiza	the close physical association between a fungus and the root system of a plant.
NAS	National Academy of Sciences.
NRTF	Naval Radio Transmitting Facility.
nymph	a stage in the development of some arthropods, between hatching and reorganization involved in attaining the adult stage.
oogenesis	the formation, development, and maturation of female gametes or eggs.
periphyton	a community of plants, animals, and associated detritus adhering to and forming a surface coating on submerged objects.
phenology	the study of temporal aspects of recurrent natural phenomena.
pupa	the life cycle stage of an insect during which the larval form is reorganized to produce the final, adult form; commonly an inactive stage enclosed within a hard shell.

regression analysis	in statistics, the estimation of the relationship between one variable and one or more other variables, by expressing one in terms of a linear or more complex function of the others.
ROW	Right-of-way, cleared corridor for location of transmitter elements.
sham ROW	a cleared corridor located on control sites which is used to duplicate possible effects from the antenna ROW on study variables.
significance	the probability that experimental results have not occurred by chance alone.
species richness	the absolute number of species in an assemblage or community.
t-test	a statistical method used for determining the significance of the difference between two means when the samples are small and drawn from a normally distributed population.
treatment site	location where primary observations or experiments are carried out and where biota are exposed to 76 or 44 Hz EM intensities at least one order of magnitude greater than its matched control site.
UMD	University of Minnesota-Duluth.

EXTREMELY LOW FREQUENCY (ELF) COMMUNICATIONS SYSTEM
ECOLOGICAL MONITORING PROGRAM: SUMMARY OF 1989 PROGRESS

1. INTRODUCTION

1.1 PURPOSE

The purpose of the Ecological Monitoring Program is to determine whether electromagnetic (EM) fields produced by the Navy's ELF Communications System will affect resident biota or their ecological relationships.

1.2 ELF COMMUNICATIONS SYSTEM

The complete ELF Communications System consists of two transmitting facilities, one located in the Chequamegon National Forest in Wisconsin and the other located in the Copper Country and Escanaba River State Forests in Michigan (see Figure 1). The Wisconsin facility is designated as the Naval Radio Transmitting Facility (NRTF)-Clam Lake, and the facility in Michigan as the NRTF-Republic.

Each facility consists primarily of a transmitter connected by long overhead wires (antenna) to buried ground terminals. Both the antenna and grounding elements are located in cleared rights-of-way (ROWs). The transmitters broadcast messages using ELF EM fields; these fields are the operational components of interest.

For the purposes of this report, EM exposure from the ELF Communications System has been divided into preoperational, intermittently operational, and operational phases. During the preoperational phase, biota received no EM exposure from the ELF Communications System. The intermittently operational phase began with the initiation of system testing; EM exposures during this phase were sporadic and at lower intensities than intended for a fully operational ELF System. The NRTF-Clam Lake was operating intermittently at the time of initiating the monitoring program in 1982; it reached a fully operational capability during the last quarter of 1985. In Michigan, intermittent operations began in late 1985; the NRTF-Republic became fully operational during October 1989. With full operational capability, EM exposures at both facilities are nearly continuous and at maximal intensity.

1.3 ELF BIOEFFECT EVALUATIONS

Research on possible EM effects to biota from exposure to EM fields produced by an ELF Communications System began in 1969. Although ecological and wildlife studies were performed in the ensuing years, the major emphasis of most ELF System-related research was on laboratory investigations. In 1977, the Navy and the National Academy of Sciences (NAS) examined the

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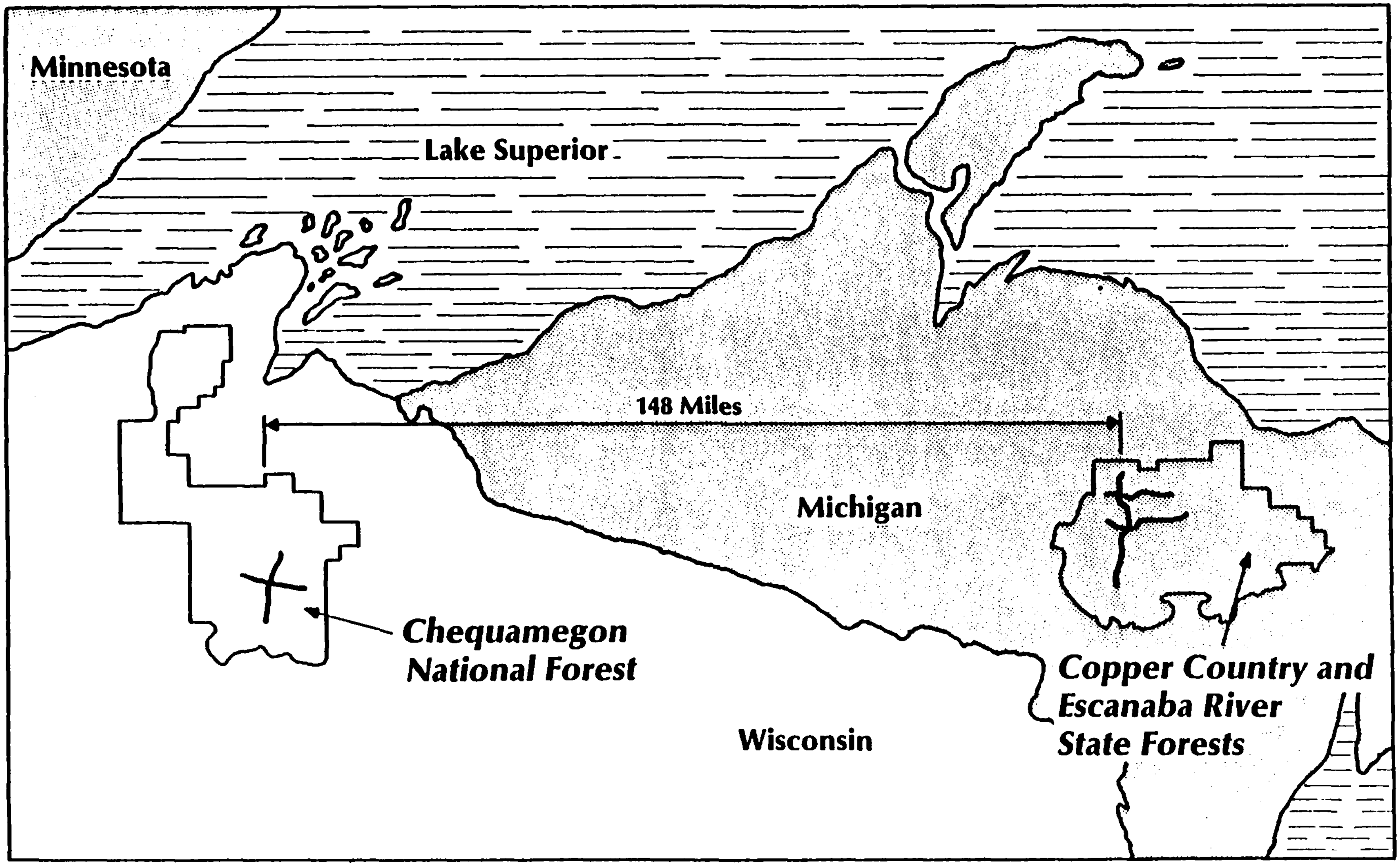

FIGURE 1. ELF COMMUNICATIONS FACILITIES IN WISCONSIN AND MICHIGAN.

information produced by these studies as well as studies performed at other ELF frequencies. Specific research simulating planned operating conditions of the ELF system, as well as research at other ELF frequencies, indicated no acute bioeffects from exposure to ELF EM fields. Those bioeffects reported were minor and/or were controversial among researchers. The Navy and the NAS concluded that adverse effects to biota from the operation of the ELF system were unlikely. After reviewing the pertinent bioelectromagnetic research reported in open literature over the 1977-1984 period, the American Institute of Biological Sciences (AIBS) reached the same conclusion as the Navy and the NAS. Despite the unlikelihood of adverse effects, the Navy, and subsequently the NAS and AIBS, recommended that a program be conducted in the ELF Communications System area to monitor for possible changes to resident biota.

1.4 MONITORING PROGRAM DESIGN

In its 1977 environmental impact statement, the Navy outlined a preliminary plan for conducting a monitoring program at those sites approved for operation of the ELF Communications System. The initial design was developed from the results of laboratory research, input from state agencies, and recommendations made by the Navy and NAS. These elements were later refined based on comments submitted in response to the Navy's draft environmental impact statement. A long-term program of *in situ* monitoring of biological and ecological variables was planned. Possible effects to pertinent biota were to be examined for by rigorous statistical analyses of spatial and temporal differences.

Study Organisms and Variables. The selection of general types of organisms for monitoring was based on their likelihood of being affected by EM fields and their ecological significance. Literature reports of EM effects, even though at higher intensities or at ELF frequencies other than those employed by the ELF System, were used in the selection process. The importance of the organisms to the ecosystems present in the area was also considered. Upon completion, the program will have examined 16 general types of organisms dominant in the upland, wetland, and aquatic ecosystems of the ELF Communications System area.

The principal criterion for selecting specific biota was their presence in sufficient numbers to ensure meaningful comparisons. Rare or endangered species have not been examined due to their low population sizes.

The program monitors for possible effects at several levels of biological organization. Organismal studies focus on the characteristics of individual (e.g., behavior, physiology). Ecological variables address levels of organization more complex than the individual (i.e., populations, communities, and ecosystems). Population variables (e.g., density, fecundity, distribution) are important because they can reflect possible subtle effects to many individuals. Community and ecosystem variables (e.g., diversity, productivity, nutrient cycling) integrate the response of many individuals and species.

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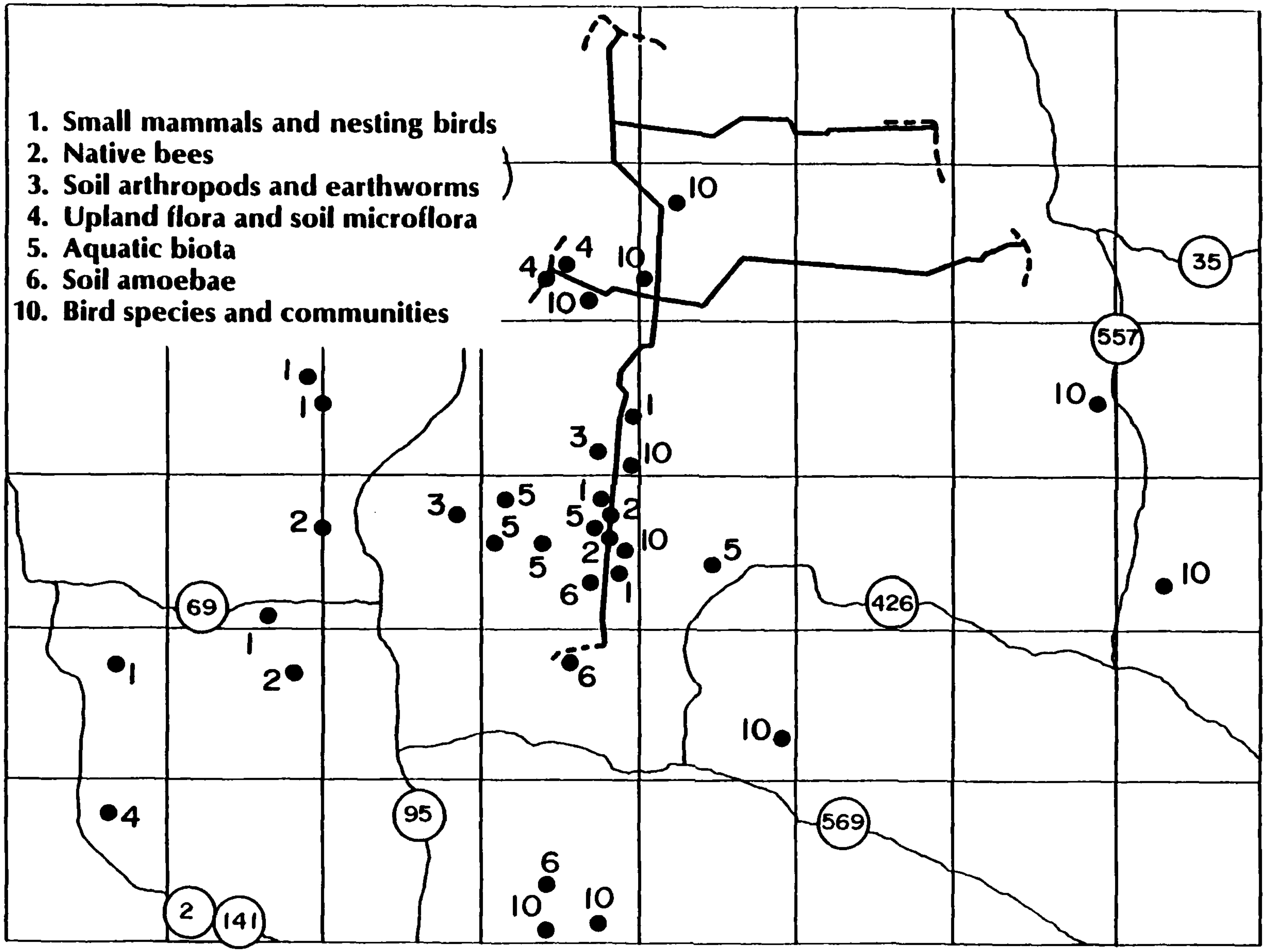

FIGURE 2. FIELD SITES FOR MICHIGAN ECOLOGY STUDIES.

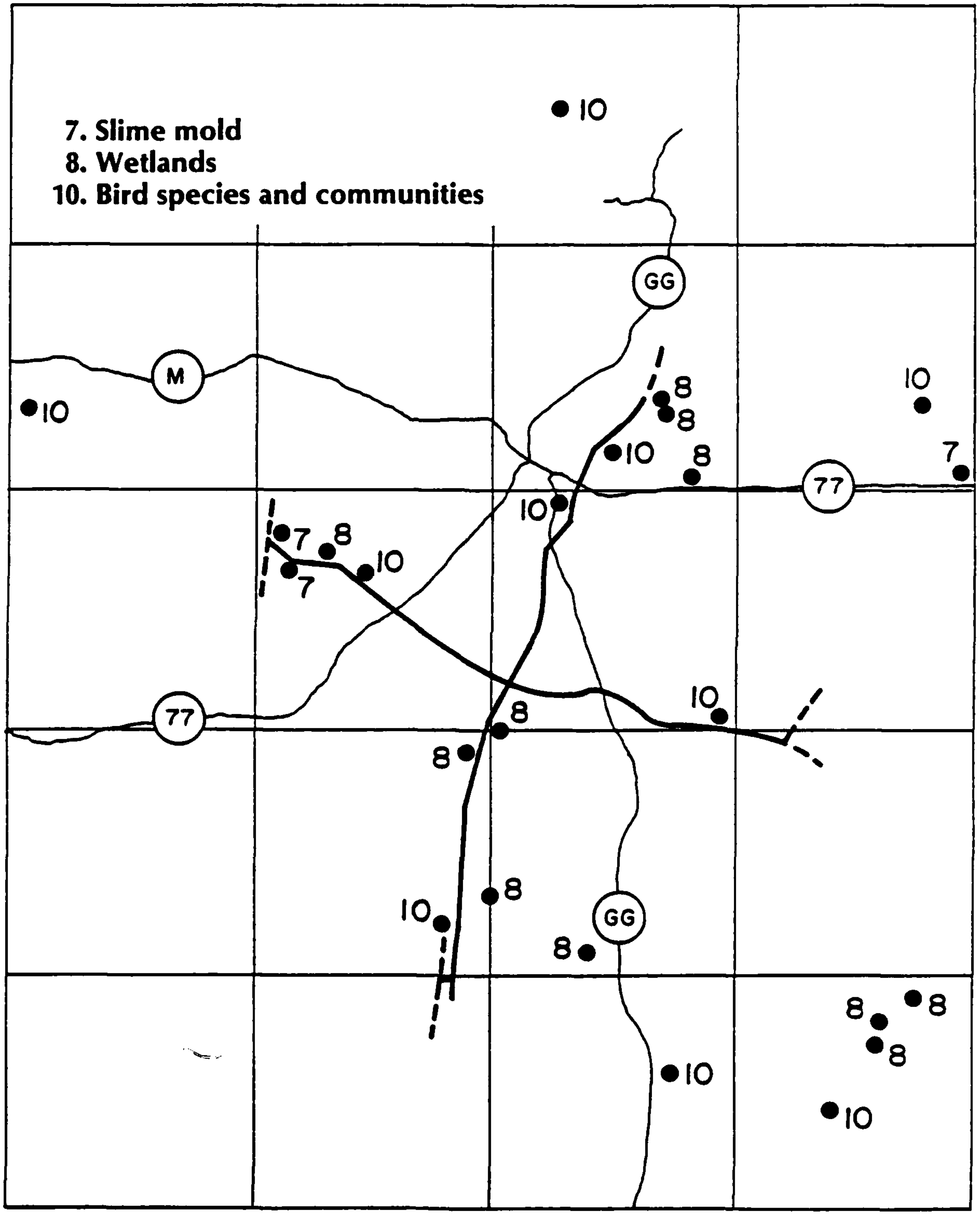

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FIGURE 3. FIELD SITES FOR WISCONSIN ECOLOGY STUDIES.

An ecological approach has been taken to examine for possible effects to the disparate species present in the area. One limitation of this approach is that ecological characteristics are highly variable, so a substantial effect must be demonstrated in order for researchers to detect it. Although narrower in scope, organismal studies have also been undertaken to provide a more statistically sensitive approach than the ecological studies. Ecological studies also provide a context for evaluating the importance of possible positive findings at the organismal level. Except for studies of slime molds, every project in the program has coupled organismal studies with monitoring at ecological levels.

Study Sites and EM Exposure. The monitoring program employs a paired treatment and control site design to examine for possible effects of ELF EM fields on biological and ecological variables. Treatment sites are positioned close to the overhead wires and grounds of the transmitters, while control sites are located at a distance from these transmitter elements (see Figures 2 and 3). Such sites have essentially matched biotic and abiotic characteristics, but purposely dissimilar ELF EM exposures. Sites have been located so as to insure that the intensity of ELF System-generated EM fields at the treatment site are significantly larger than those at the control site. Data collected at the control site represent the effects of natural environmental conditions, whereas data collected on the treatment sites represent the effects, if any, of natural conditions plus exposure to higher EM intensities relative to those on the control.

As multiyear studies are being performed, temporal comparisons of variables are also possible. Comparisons of data collected during preoperational (no EM exposure) with data collected during the intermittent and operational phases of the NRTF-Republic have been made for Michigan studies. A preoperational data base does not exist for studies in Wisconsin; therefore, comparisons have been primarily spatial.

Period of Performance. The period of performance for the program had to address several temporal aspects, including organismal generation times, time of full operational capabilities, and non-ELF cyclic changes in variables. The actual and proposed schedules for studies in Michigan and Wisconsin are presented in Figures 4 and 5.

EM effects on resident biota, if any, will be subtle and therefore will not be expressed at the population or community levels for several generations. Long-lived animal species, in particular, have life cycles longer than two years. If adults are less susceptible than younger individuals, one would anticipate a time lag until lack of recruitment of young individuals is reflected in processing rates (e.g., decomposition) and/or community composition (e.g., diversity). Thus, if ELF EM fields affect the development of the young in such species, possible effects may not be obvious for several years.

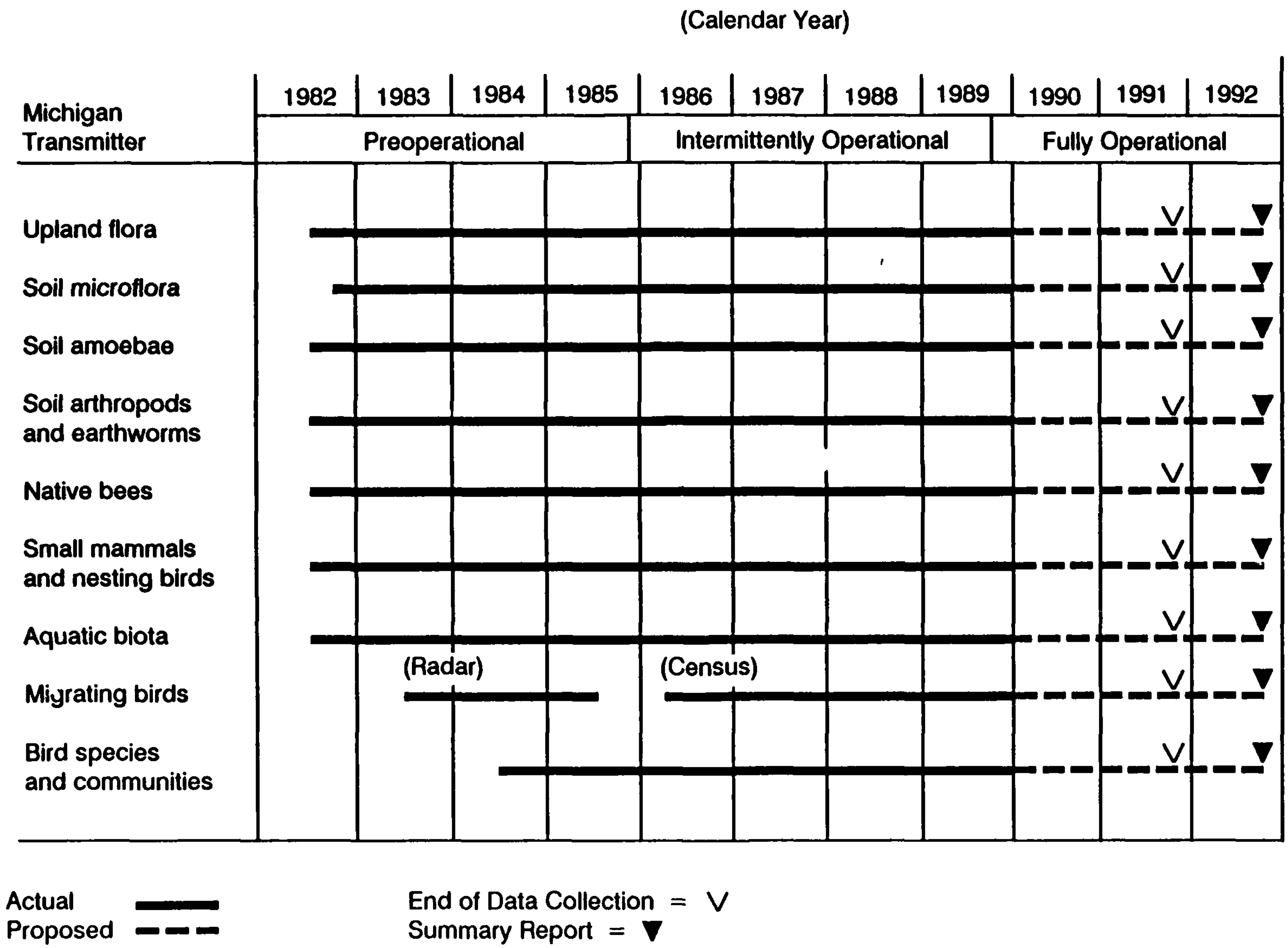

FIGURE 4. SCHELDULE FOR MICHIGAN STUDIES.

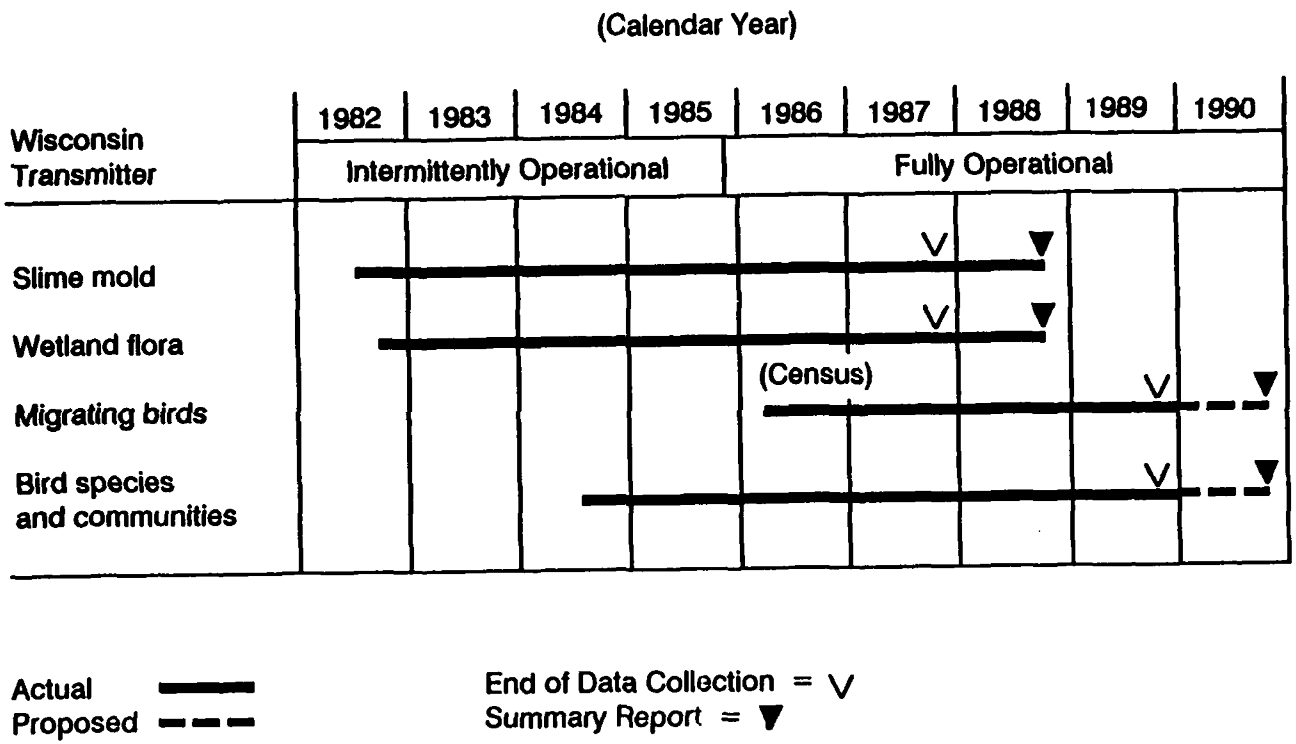

FIGURE 5. SCHELDULE FOR WISCONSIN STUDIES.

Early studies of the ELF Communications System lacked a preoperational data base, and were performed while the (then) Wisconsin Test Facility was intermittently operated at less than full power. In order to appropriately examine for possible effects, data must be collected while the ELF System is in a fully operational mode. The current period of performance has provided two to four years for data collection during the operational phase of the NRTF-Clam Lake and three years for data collection at the NRTF-Republic.

1.5 PROGRAM DEVELOPMENT

Concurrently with approval to complete construction of the ELF Communications System, the Department of the Navy funded the Ecological Monitoring Program. Early in 1982, a competitive process was initiated to select subcontractors to participate in the program and by mid-summer preliminary work began for studies of upland flora, soil microflora, soil amoebae, soil arthropods and earthworms, native bees, small mammals and nesting birds, aquatic biota, and slime molds. Unsolicited proposals for studies of wetland flora and migrating birds were funded the following year. These latter two studies, together with the eight studies selected in 1982, constituted the program in 1983.

In both 1983 and 1984, peer reviewers expressed serious doubts that the then-ongoing radar studies of migrating bird disorientation could be used to successfully detect possible effects of the ELF Communications System. The radar study was replaced with a census of migrating birds in 1986.

The major objectives of each study during the early years of the program were the selection of study sites, the validation of assumptions made in the proposals, and the characterization of critical study aspects. These objectives encompassed such activities as:

- identification of biota
- assessment of data collection protocols
- quantification of spatial and temporal patterns for each variable
- assessment of parameter variability.

As these tasks were accomplished, increasing emphasis was placed on the collection of data and the refinement of statistical protocols.

In Wisconsin, studies of wetland flora and slime mold have been completed, and a summary report for each will be distributed during 1990. Both studies found some significant differences between sites in the variables examined; however, the significant findings showed no consistent pattern among parameters, species, nor sites. Temporal changes did not match energization of the transmitter, and in several cases significant findings were not supported by additional statistical analyses. ELF researchers concluded that there were no ELF EM bioeffects on wetland flora or mold metabolism.

Bird studies were performed in both Wisconsin and Michigan. Wisconsin studies were completed as scheduled during 1989 and showed some consistent, significant differences between sites for several bird population characteristics. Even though census transects were randomly selected, more coniferous, lowland habitat was found on treatment transects than on control transects. Significant differences between sites in bird community parameters have been attributed to the differences in habitat. A summary report will be prepared and distributed during late 1990 or early 1991. Collection of data on bird communities and species in Michigan will continue through 1991.

In Michigan, studies continued to collect data and further develop their analytical protocols during 1989. Several variables have shown significant differences between the operational phases of the NRTF-Republic; however, there were no corresponding significant differences between sites. The significant temporal differences have been attributed to a multiyear drought, which started at the same time as intermittent operation of the facility in 1986. Other studies in Michigan have not shown spatial or temporal differences attributable to ELF EM fields.

Wildlife surveys near the NRTF-Clam Lake have also been performed by the U.S. Forest Service. Although not an intergral part of this program, the results of these surveys are generally applicable to the program objectives. Annual surveys of ruffed grouse, eagle, and deer populations were initiated in 1974, 1975, and 1982, respectively. No effects on these populations from the operation of the ELF Communications System were detected, and the studies were concluded after the 1986 surveys. A summary of protocols and data can be found in Reference 21.

2. BIOLOGICAL/ECOLOGICAL STUDIES

This section summarizes the progress for each of the eight studies that constituted the program during 1989. A more detailed presentation of study protocols, methodology, and progress is given in individual project reports.

The general types of biota being examined are used as subsection titles, while specific study elements are presented as underlined run-in titles in each subsection. In order to simplify presentation of statistical results, any difference described as "significant" had a significance level of 5 percent ($P < 0.05$).

2.1 UPLAND FLORA

Forest vegetation is the dominant biota in the ELF Communications System area. The production of organic compounds by vegetation and the subsequent degradation of these compounds make up the main method for the transfer of energy and nutrients to other organisms. Indeed, organic matter turnover and distribution are regarded as major determinants of the forest ecosystem structure. Because the production and distribution of organic matter have been shown to be measurably affected by anthropogenic factors, these processes and associated organisms are being monitored for possible effects from the ELF Communications System. Important aspects in the production of organic compounds by upland vegetation are presented here; those organisms and processes important in organic matter decomposition are addressed in Sections 2.2, 2.3, and 2.4.

In order to examine for possible changes in upland productivity and health, the following elements are being examined:

- growth rates of established tree stands and pine seedlings
- phenological events of trees, herbs, and mycorrhizal fungi
- numbers and kinds of mycorrhizae on red pine seedlings
- foliar nutrients and litter production
- insect damage, disease, and ambient environmental factors.

The experimental design for these studies is best described as a split plot in space and time. Two treatment sites are located so that one site is adjacent to an antenna element, and the other, adjacent to a ground element of the NRTF-Republic. A single control site is located more than 28 miles from the nearest antenna element. The antenna and control sites each consist of overstory tree plots (existing pole-size stands), plots planted with red pine, and plots of herbaceous plants. The grounding treatment site consists of plots planted with red pine only. No tree stands or herbaceous plots were established at the ELF System grounds because the buffer strips required to eliminate "edge effects"

would have placed the study flora at too great a distance from the grounding elements for meaningful EM exposure. Since successive measurements are made on the same plots and individuals without rerandomization over a long period, the experimental design must account for time. Therefore, a combined analysis is made to determine both the average treatment response (site differences) over all years, and the consistency of such responses from year to year, particularly preoperational/operational comparisons.

Tree Growth. Studies have shown that tree growth is sensitive to environmental perturbations other than EM exposure. In order to monitor for possible similar effects from operation of the ELF System, tree growth on existing hardwood stands and pine plantations is being monitored.

As one of the most accepted tree growth measurements, diameter growth is being measured for abundant tree species in the ELF System area (maple, oak, birch, and aspen). Permanently installed dendrometer bands provide continual measurement of diameter growth for each tree in the stand. Other parameters related to hardwood tree productivity such as stand structure, ingrowth, disease, and mortality are used in data analyses; however, these parameters are not specifically addressed in this summary. The magnitude and pattern of diameter increment changes were examined for each species in several ways. Split-plot analysis of covariance was used to compare diameter changes. Models were used to quantify the relationships between tree, site, climate, and tree diameter growth variables. Residual variance and expected growth pattern generated from the model were then used in further analyses.

Except for oak, analyses of covariance showed no significant differences between sites or years (1985-1988) in the growth of the four tree species. Despite significant differences between years for oak, the pattern was not related to energization of the NRTF-Republic. Several of the natural factors used in the statistical analyses correlated with EM field intensities. A critical requirement in covariate analysis is that the covariates, or natural factors, be independent of the treatments or EM field intensities. Since there is no physical basis for the relationship, analyses of covariance were used; however, acceptance of the results should be deferred until additional data are collected.

Growth models for each of the tree species supplemented the analysis of covariance. The variance of diameter growth unexplained by the model (residuals) was then compared to EM field exposure. There were no indications of ELF System effects on oak, birch, or maple, but aspen on the antenna site showed a trend of increased growth that did not occur on the control site. Growth differences were not explainable by differences in site or stand conditions.

Young trees experience more rapid rates of growth than older trees; therefore, in addition to monitoring older trees, red pine seedlings were examined for possible growth effects due to exposure to ELF EM fields. After their planting in 1984, pine seedlings at each site were randomly selected for

survival and growth studies. For these analyses, each of the marked seedlings was measured at the end of their growing season (1984-1989) for basal diameter, total height, and terminal bud length. Information on microsite variables, physical damage, presence of multiple leaders, and number of neighboring seedlings was also collected to aid in interpretations of the statistical analyses. In order to describe the growth pattern, a subsample of seedlings was selected from the marked group for weekly height growth measurements. As for the hardwood trees, total annual height and diameter were analyzed through a split-plot analysis of covariance, while the pattern of height growth within a season was examined through the use of a height growth model.

Covariance analyses of total height growth of red pine showed significant differences between years (1986-1988), but no significant differences between sites or site/year interactions. The previous year's air temperature, water-holding capacity of the soil, and soil nitrogen were used as covariates in the analyses. The first two covariates were significantly correlated to one or more of the EM fields at the treatment sites; therefore, the results of the covariate analysis were further examined using models. After analysis of the residuals (observed vs. model predicted tree height), significant differences between years remained.

No significant differences occurred between sites or between years (1985-1988) in the diameter growth of red pine, but there was a significant site/year interaction. As in the previous analyses, some of the covariates were correlated with EM exposures. Further examination using multiple range tests showed no consistent pattern of differences between the sites. Correlation analyses indicated a weak, but significant, relationship between EM exposure and total seasonal diameter growth. Height growth models based on incremental seasonal growth of the leading shoot of the red pine trees were used to evaluate patterns of seasonal growth. No significant differences between observed and predicted height growth patterns were found for the model's residuals over the period 1986-1988.

Some of the analyses indicate possible EM effects on the growth of aspen and red pine; however, during the periods examined, EM intensities have been increasing (due to increased transmitter amperages) coincidental with increasing air temperatures and below-average rainfall. Although no physical basis exists for connecting these latter two covariates with EM fields, some significant correlations have been found between them. As a result, findings of no significant differences between sites are not yet credible. Similarly, correlations between the growth parameters of rapidly enlarging trees and EM exposures are suspect. As the study period lengthens, the expectation is that EM intensities at the study sites will remain constant from year to year and recent trends in temperature and rainfall will change. The relationship between EM fields, covariates, and growth parameters will probably not remain correlated over the term of the study. This wiii validate the use of covariate analyses and allow more confidence in the monitoring results.

Mortality of pine due to *Armillaria* root disease, first documented in 1986, continued during 1989. As seedling vulnerability is increased by stressors, EM exposure is being examined as a possible factor in the incidence of pine mortality. At present, this disease is the only natural source of mortality to the pine seedlings. The frequency of annual mortality had increased from 1986 through 1988, but declined in 1989. In order to make proper statistical comparisons between the sites, pertinent covariates are being identified and measured. These include identification of *Armillaria* clones, numbers and basal areas of hardwood stumps, rock content of soils, mean seedling height, and mean terminal bud length. Results of the completed analyses will be presented in the 1990 annual report.

Herbaceous Plants. Like the trees, herbaceous plants are sensitive to environmental perturbations and are an important component of the habitats found near the ELF Communications System. Possible effects to these short-lived plants are being monitored, and the results of ongoing studies are presented in this section. Possible effects to other (long-lived) species (i.e., trees) are presented in sections dealing with Tree Growth and Litter Production.

The starflower, an abundant herb in the ELF Communications System area, has been selected for monitoring. Select phenological events, as well as morphological characteristics, of naturally growing starflower plants are being followed each year on plots at the antenna and control sites. Timing aspects related to leaf expansion and the onset of flowering are the main phenological events being examined. Morphological characteristics being monitored include number of buds, number of flowers, number of fruit, and maximal leaf area.

Analyses of covariance showed no significant differences between sites in stem expansion (cm/time period), leaf expansion (cm/time period), or leaf area expansion (cm^2/time period). Similar analyses showed significant differences between years (1985-1989) for stem and area expansions. There were no significant interactions between sites and years for these three variables. The covariates used included solar radiation, soil temperature, air temperature, and basal area of adjacent trees (shading). Other climatic factors used as covariates failed to explain any of the significant differences between years.

During 1989, the proportion of plants flowering at the control site (12%) was significantly lower than in previous years (>20%); however, there was no significant differences between years in the proportion of plants flowering on the treatment site. These results indicate a possible microclimatic change at the control or differences due to handling. The latter possibility was examined during 1989. No significant differences between "handled" and "unhandled" plants were found for stem length, leaf length, and leaf width.

Morphological characteristics of the starflower monitored included number of buds, flowers, and fruit per plant. Other differences in morphological variables were noted. Since similar relationships were

seen in previous years, the plants were examined for possible clonal differences between the populations of starflowers at the study sites. Plants and soils were collected at both sites and placed in the same light and temperature regime in a greenhouse at Michigan Technological University (MTU). A significantly greater mean number of leaves and leaf width was found on those plants collected from the antenna site. No significant difference was evident between treatment and control plants for other morphological characteristics. These studies will be continued during 1990.

Leaf area was also analyzed by destructive measurement of plants leaves collected at each site over the period (1986-1989). Using regression analyses, linear equations were fit to observations of leaf area; coefficients (slope and intercepts) were then examined for differences between sites and years. Despite significant differences between years (1986-1989), there were no significant differences between sites nor any significant site/year interactions.

To date, the intersite pattern of phenological events and morphological characteristics of herbaceous plants has shown no effects attributable to intermittent exposure to EM fields generated by the NRTF-Republic.

Mycorrhizal Populations and Root Growth. Mycorrhizal fungi form a symbiotic relationship with the roots of higher plants such as trees. The fungi utilize organic compounds synthesized by the tree for their growth and to "forage" for minerals and water in the soil. In turn, the fungi provide the tree with minerals and water more efficiently than the tree roots alone. This relationship is considered essential to the satisfactory growth of nearly all tree species. Because the growth of fungal mycelia is dependent on physiologically produced intracellular electrical currents, other sources of electrical current, such as the ELF Communications System, may have an effect on the fungi and, indirectly, on trees. The population dynamics of mycorrhizae occurring on pine trees are being examined.

Populations are being characterized by the frequency of occurrence of mycorrhizal types and the number of mycorrhizal root tips per gram of red pine seedling. In 1989 as in previous years, Type 3 mycorrhizal were the most common, Type 5 the second most common, and Type 6 the least common encountered at the study sites. The total number of mycorrhizae has declined over the period 1985-1988 with a slightly greater number at study sites in 1989 than in 1988. The total number of mycorrhizae present in 1988 and 1989 was significantly lower than in the previous three years. This interyear pattern is relatable to temperature and precipitation and/or seedling age.

Multiple analyses of variance and covariance of all data collected over the 1985-1989 period show no significant differences between sites or interaction of sites and years in the number of mycorrhizae per unit weight of red pine seedling root. Both analyses showed significant differences between years (1985-1989). Detection limits calculated from 1985-1987 data indicate that a dissimilarity of at least 10 to 15 percent will be necessary to recognize a significant difference between sites, whereas

an overall disparity of 15 to 25 percent will be required to identify a significant difference between years by site. Findings to date fail to show any measurable effects on mycorrhizal symbiosis between pine and fungi exposed to ELF EM fields.

Foliar Nutrients and Litter Production. The purpose of this element is to examine the nutrient content of growing foliage, the total weight of litter produced, and the nutrient content of (three) litter components. The former monitors for possible timing and magnitude of differences, while the latter two components provide estimates of seasonal canopy production and nutrient inputs to the decomposition system (see Section 2.2).

Actively photosynthesizing red oak foliage was examined for its content of nitrogen, phosphorus, potassium, calcium, and magnesium. Covariate analysis of data collected over the period 1985-1988 showed significant differences between sites in the potassium content of oak foliage and significant differences between years for all five nutrients. Covariates included air temperature, soil temperature, and soil nutrients. Minimum detection levels for differences in the nutrient content of red oak foliage ranged from 4 to 24 percent of the mean. Multiple range tests showed that in all cases, significant year and site differences occurred prior to intermittent energization of the NRTF-Republic.

Covariate analyses of pine foliage nutrients showed significant differences between sites in nitrogen and phosphorus content, and significant differences between years for all nutrients. Mycorrhizae per gram of root weight, soil nutrients, and climatic variables were used as covariates in the statistical analyses. Many of the covariates proved to be significantly correlated to EM exposures.

Litter was collected in traps on existing hardwood stands at the antenna and control sites. The litter was dried, sorted, and weighed according to the following components: foliage, wood, and miscellaneous. A subsample was taken to determine the nutrient content of the litter. Analysis of covariance showed no significant differences between sites or site/year interactions (1985-1989) for the total weights of the three litter components examined. There was a significant difference between years in the total weight of foliage, but no differences between years for the weight of the wood or miscellaneous categories. Soil and air temperature were used as covariates. The detection limits for interyear and intersite differences in total foliage weights (10 to 19 percent of the mean) have proven to be more sensitive than the wood (28 to 56 percent) or miscellaneous (33 to 62 percent) components of the litter.

Average nutrient concentrations (five) for litter components (three) and tree species (four) showed no site differences when data were combined. Except for the calcium content of wood and the potassium content of red maple, analyses of covariance showed no significant differences between sites in the nutrient content of litter components or tree species, but several differences between years in the nutrient content of all litter and species categories. Covariates used in the analyses included air

temperature, soil temperature, and soil nutrients. Minimum detection levels for litter nutrient content by component or by tree species ranged from 2 to 25 percent of the mean. Significant differences were further examined to determine if nutrient content had changed in response to NRTF-Republic operation. Multiple range tests using covariate adjusted means showed some of the differences between sites existed before initiation of intermittent operation at this facility.

Results to date indicate that intermittent operation of the facility has had no detectable effects on the nutrient content of actively photosynthesizing foliage, production of tree litter, or the nutrient content of litter.

2.2 SOIL MICROFLORA

Soil microflora (bacteria and fungi) play a key role in the maintenance of upland forest ecosystems such as those in the ELF Communications System area. They degrade organic molecules present in litter and influence the size of other microbial populations that have important influences on the nutrition of plants. Anthropogenic factors that disrupt soil community processes may directly alter the flow of nutrients to vegetation and thus indirectly affect the forest community. The objectives of this element are to monitor for possible effects from EM fields produced by the ELF Communications System on populations of streptomycete bacteria associated with plant roots and to examine overall rates of litter decomposition.

Upland flora (producers) and soil microflora (decomposers) form a natural assemblage. Although these elements are being examined as separate projects, both subcontractors are with the Department of Forestry, Michigan Technological University, and both share common study sites and ambient monitoring systems. Bacterial population and decomposition objectives are closely related to the mycorrhizal and litter production objectives described in Section 2.1. Studies of other important soil organisms can be found in Sections 2.3 and 2.4.

Streptomycete Bacteria. Streptomycetes have been reported to be involved in the nutrition of mycorrhizae and may indirectly influence trees through their production of antibiotics or growth factors. The purpose of this element is to characterize and enumerate streptomycete bacteria associated with red pine mycorrhizae (see Section 2.1).

Samples were taken monthly from May through October from pine trees located on plantations at the antenna, ground, and control sites. Sample sizes and protocols used during 1989 were the same as used in previous years. Macerate plate count data for morphotypes and population levels associated with Type 3 mycorrhizal fine roots were expressed as numbers per gram of root. Samples were also analyzed for bacterial-isolate ability to degrade important organic molecules. All data were logarithmically transformed prior to statistical analyses. Two-way analysis of variance was used to compare

sampling dates and study sites within 1989. Three-way analysis of variance was used to compare years (1985-1989), as well as sites and sampling dates. Whenever these analyses showed significant differences, multiple comparisons were conducted by least square mean procedure to determine the relationships of the variables. Covariates, particularly weather-related parameters, were also included to further examine differences between sites, years, or sampling dates.

During 1989, a statistically significant difference occurred between the ground and control sites in the number of morphotypes found there; however, there was no difference between the antenna and control sites. Years prior to 1989 showed no significant differences between any of the sites. When 1989 data were analyzed further using select weather variables as covariates, no significant differences were found between any of the sites. Analyses of variance and covariance both showed significant differences between years (1985-1989) in the annual mean number of morphotypes. Generally, the annual mean number of morphotypes declined from 1985 through 1987, but the number has essentially remained the same since 1987. Estimates of the magnitude of significant differences in mean values that are detectable 95 percent of the time were 5-6 percent for intersite comparisons and 9-12 percent for interyear comparisons. Based on these estimates, the loss of a single morphotype would be detected.

Of the 20 morphotypes isolated in 1989, morphotype B was again the most common at all sites. The most notable change was a decrease in the incidence of morphotype F, which had a high frequency of isolation prior to 1989. The fact that the ability of the isolates to degrade select organic molecules has not changed over the last three years indicates little change in streptomycete activities.

During 1989, as in the past, analyses of variance and covariance showed no significant differences between sites in the numbers of streptomycetes isolated from Type 3 mycorrhizae. Analyses of variance showed significant differences in numbers of isolates between years. Least square mean comparison tests indicated population levels to be significantly higher in 1987 and 1988 than during 1985, 1986, and 1989. There were no significant differences among the years within each of these two groups. Interyear comparisons using weather variables as covariates showed no significant differences between years. ELF researchers estimate that a statistically significant shift of less than 1 percent in the annual mean number of streptomycetes can be detected 95 percent of the time when using covariate analysis.

Similar, relatively stable streptomycete populations have become established on pine trees planted at three study sites. Statistical analyses indicate no measurable EM effects on streptomycete populations associated with red pine roots from operation of the NRTF-Republic.

<u>Litter Decomposition</u>. Mass loss of leaf litter is a sensitive index of organic matter deterioration and has traditionally been a measure of the overall functioning of the litter community. This study element monitors the decomposition of leaf litter from three species of trees found in the ELF

Communications System area. The species are northern red oak and red maple, which are common, and red pine, which are found as scattered specimens throughout the area.

Leaf litter is collected each autumn from a single location. The leaves are either archived for possible future reference, analyzed for nutrient content, or weighed and enclosed in nylon mesh envelopes for emplacement at study sites. The envelopes emplaced at study sites contain either individual leaves or bulk foliage samples of a single species. All samples are emplaced in December. A few samples are retrieved each month over the period April through November of the following year. Retrieved samples are reweighed, and data are expressed as the percentage of original dry matter mass remaining. Mass loss data from 1985 through 1989 are complete. Nutrient data for litter collected during 1984-1986 and alternate months in 1987 and 1988 are also complete. Chemical analysis of litter collected during 1989 is pending.

After arcsin square root transformation, data analysis of litter mass loss was essentially the same as used to examine streptomycete populations--i.e., 1985-1989 data were examined by analysis of variance and analysis of covariance for differences between sites and between years. The original approach of also using nutrient fluxes as independent decomposition variables was changed in 1988, and subsequently the nutrient parameters have been used as covariates in some statistical analyses.

Analyses of variance failed to show any pattern consistent with EM exposure regimes. Of the 10 possible intersite comparisons for plantation sites (three), decomposition on the control site was equal to the treatment sites in two of the comparisons, greater than treatment sites in four of the comparisons, and less than one of the treatment sites in four of the comparisons. On hardwood stands (two), decomposition at the control site was equal to that on the treatment site in four comparisons and less than the treatment site in four comparisons. Similar analyses found many interyear differences; however, no preoperational/operational pattern was apparent. Use of initial leaf density and select weather variables as covariates failed to explain any of the intersite, or interyear, differences. Researchers are 95 percent confident of detecting 9-12 percent differences in the means used for comparisons.

Many of the significant differences detected can be attributed, in part, to very low variability of the data. Although some of the findings are statistically significant, the actual differences in decomposition rates are so small as to be biologically inconsequential. Nevertheless, analyses will continue to be conducted to examine for differences that are both biologically meaningful and statistically significant.

Covariates to be evaluated during 1990 include initial lignin and nutrient content, nutrient content of monthly samples, soil and vegetative cover, litterfall characteristics, and integrated weather variables. For the last variable, one covariate related to actual evapotranspiration will be constructed to simultaneously consider temperature, precipitation, and water-holding capacity of the surface soil. Though

nutrient contents of litter samples have not yet proven useful, lignin content determinations have been completed and will soon be evaluated as a covariate. With the planned intensive plotting of EM intensities across study sites, EM intensities will be estimated for each litterbag location and also used in analyses of variance.

2.3 SOIL AMOEBAE

Soil amoebae are common soil organisms that are predators on bacteria. Bacteria, in turn, are important to the soil ecosystem because of their ability to mobilize nutrients needed for plant growth. To the extent that protozoa affect the number and types of bacteria in the soil, they also become a potentially important factor in soil fertility. Studies on protozoa and other closely related organisms have suggested possible EM effects on characteristics such as orientation, growth, and physiology.

In order to examine for possible effects from the operation of the ELF Communications System, the following aspects of soil amoebae are being studied:

- species and strain characteristics
- population size and activity
- growth and feeding.

In addition, selected elements indicative of soil fertility are being monitored.

Studies on soil amoebae are being performed at three study sites in Michigan. One treatment site is located adjacent to an overhead antenna wire of the NRFT-Republic; the other is located adjacent to a buried grounding element of the facility. A third site, the control, is located about nine miles from the nearest ELF System element.

Species and Strain Characterization. During 1989, eight types of amoebae (various generic and species levels) were isolated using soil enrichment techniques. To date, no differences between years or between sites have been reported in the types of amoebae present.

In previous years, the genetic diversity within a single species of soil amoeba, *Acanthamoeba polyphaga*, was determined by isoenzyme analysis. Budget constraints prohibited continuing this aspect of the study during 1989. Analyses of 1985-1988 data showed no significant differences between sites in the genetic diversity of strains of *A. polyphaga*. Nevertheless, the genetic diversity of this species has apparently decreased over the 1985-1988 period probably due to adverse precipitation conditions.

Population Size and Activity. The size of the amoeba population is considered an ecological variable likely to influence the functioning of the soil system.

Soil samples for population studies were taken with a coring device. Coring locations within study sites were determined randomly, using a numbered grid system and a random number generator. The soil profile at study sites is typical of northern hardwood soils--i.e., with a sharp difference between

the upper, organic horizon and lower, mineral horizon. In a typical core the 1- to 2-in. organic horizon is taken as one sample, and the top 2 in. of the underlying mineral horizon is taken as a second sample. A soil-dilution counting technique is used to determine the population size of each sample.

Studies to date have shown that the total amoeba population at any given moment consists of both vegetative (actively reproducing) and encysted forms. During both the 1984 and 1985 growing seasons, marked cyclic changes occurred in the total number of amoebae present; the number of vegetative stages and total amoebae often increased or decreased by two orders of magnitude over short periods of time. Since 1986 the occurrence of fluctuations and the overall numbers of amoebae have been relatively small. Although preliminary results indicate that 1989 population sizes are similar to those seen for the 1986-1988 period, a statistical comparison between years was not reported.

Preliminary examination of 1989 population data using analysis of variance showed a significant difference between sites in the total number of amoebae and the total number of cysts present in the organic layer of the soil during July. The number of vegetative stages increased at the antenna site but not at the other sites. The cause of increased amoeba numbers was not determined. Most other comparisons were not statistically significant.

<u>Growth and Feeding Activity</u>. The purpose of this element is to determine the *in situ* growth and feeding activity (i.e., predation on bacteria) of soil amoebae in buried culture chambers.

This study element involves suspending a known species of amoeba (*A. polyphaga*) and a food bacterium in a physiological saline, all contained in a culture chamber. In order to simulate electric fields and currents present in the surrounding soil, the chambers are connected to buried collecting electrodes. Culture media with bacteria are replaced on a two- to three-week cycle using EM exposed amoebae from old cultures to inoculate the new media. Periodic counts of amoebae were made to determine changes in the number of organisms. A logarithmic transform of the growth data provided a straight-line plot (numbers over time), which was then quantified by regression analysis. Using a modified t-test, the resulting slopes of the lines were compared to examine for statistically significant differences between sites. Beginning in 1988, the genetic heterogeneity of the cultured amoebae was determined at the onset (June) and termination (October) of the experimental period.

In 1989, as in 1988, there were no significant differences between sites in the growth, or for the isoenzyme heterogeneity, of the cultured amoebae. The generation time for all cultures ranged from 16 to 18 hours.

2.4 SOIL AND LITTER ARTHROPODS AND EARTHWORMS

Arthropods and earthworms play a major role in the decomposition of vegetation. These invertebrates shred plant material such as leaves and redistribute the remains in the soil habitat. The

vegetative remains are then further degraded by soil microflora (see Section 2.2). For the purpose of detecting possible effects of the ELF Communications System on major agents of litter decomposition, this project is monitoring both the structural and functional aspects of the litter and soil invertebrate community.

The project employs one treatment site located adjacent to the antenna ROW at the NRFT-Republic and one control site located at a distance west of the antenna. Both sites are situated in a maple-dominated deciduous forest. Although the sites display faunal differences, they have similar soils, vegetation, and microclimate.

In order to address faunal differences between sites, community indices and the characteristics of major populations common to both sites are emphasized in these studies. In addition to dominant groups, populations representing various roles in the soil habitat, such as predators and detritivores, are examined. To accommodate the various roles of the soil fauna, intersite comparisons of ecological equivalents and/or preoperational and operational comparisons of populations unique to the treatment site are planned. Litter decomposition rates will provide an overall indication of the functional aspects of the soil community.

Surface-Active Arthropods. This element examines the major arthropod fauna utilizing the surface layers of the soil at each site.

Diel and seasonal activity patterns of surface-active arthropods were assessed by consecutive, day and night, pit-trap samples taken once a week. In order to increase catches of surface-active arthropods, pit traps were provided with barriers that increased the effective area sampled by diverting moving arthropods toward the pit. Major groups trapped were springtails, mites, and ground beetles. The following paragraphs present information on data collected over the 1985-1988 period.

Since 1985, 36 species of springtails have been identified with about 75-85 percent of the species shared between sites. Marked differences still prevail between sites and between years in the diversity of the springtail community. Based on the data collected to date, the sites also differed in the relative dominance of major species, as well as in the occurrence of a few rare species. There were large differences between years and sites in the total number of springtails trapped. Nevertheless, continued monitoring of density and diversity will be used to compare activity patterns between sites and years.

Monitoring of the activity patterns and density of three abundant species of mites continued during 1989. Generally, intersite seasonal activity patterns remain highly correlated for all three species.

Since 1985, 24 species of ground beetles have been identified. The number of species has remained relatively constant over the 1985-1988 period and is similar between sites. Preliminary examination using linear regression statistical techniques, of the pattern of numbers trapped throughout

the season showed no significant differences between sites within a given year. However, in 1988 the total numbers trapped at the control site were markedly lower than those trapped at the treatment site. The reason for this dramatic drop is unknown. In addition to monitoring diversity and trappable numbers (activity pattern), researchers are examining fecundity (number of eggs per female) as an indicator of the physiological state of adults. Preliminary analyses of two beetle species show no significant differences between years or sites in the fecundity of the beetle.

Soil and Litter Arthropods. The population and community dynamics of soil and litter arthropods are being determined from samples taken during the growing season (May-October). Litter and soil are sampled separately. The arthropods are then extracted by heat and sugar flotation techniques. Springtails and mites are the most numerous taxa in the litter and soil of both sites and are the major groups of interest. At the time of reporting, data were available for the period 1984-1988.

Since 1984, 73 species of springtails have been identified at the study sites, and in any given year 45-55 species have been collected. The diversity of the springtail communities shows significant differences between sites and years. Over the 1986-1988 period, diversity indices have declined in a similar manner at both sites. Springtails are more abundant on the control site than on the treatment site. Temporal fluctuations in total numbers and developmental stages are highly correlated between sites. Several species continue to occur in large numbers at both study sites. Two species with high correlations in intersite densities were selected for more intensive characterization. The population structure of one species (1984-1987 period) was statistically examined during 1989. There were no significant differences between sites or years in the mean number of individuals constituting three developmental stages (hatchlings, juveniles, or adults).

Identification and enumeration of all mite species found in the litter and soil is an intractable problem; therefore, three relatively abundant species have been selected for this monitoring effort. Year-to-year changes in density are similar at both sites for each of the three species. Two of the three species also showed a highly correlated population composition (density of larvae, protonymphs, deutonymphs, and adults) between the study sites. Monthly frequencies of developmental stages of two species were analyzed in detail using analyses of variance. Both species of mites showed the same results: significant differences between years but not between sites. The absence of significant site/year interactions further indicated that between-year differences occurred in parallel at both treatment and control sites.

Earthworms. The purpose of this element is to examine the major earthworm fauna inhabiting the soil and litter of the study sites.

Earthworms were extracted from litter using weak formalin, and those in soil were obtained by hand sorting followed by wet sieving. Earthworm samples were taken at regular intervals, May through

October. Eight species of earthworms have been identified at the study sites. As expected, species diversity indices are low but are comparable to worm communities found in similar latitudes and habitats. Seven of the eight species are found at both treatment and control sites, but their densities are markedly different between sites. If current trends of increasing density of rare species continue, sites are expected to become more similar.

Year-to-year densities of worms vary as functions of new cocoons produced, old cocoons hatched, and the effects of ambient conditions on reproductive adults. Although there were significant differences between years in cocoon densities and numbers of immature worms, recruitment and growth patterns continued to be similar at both treatment and control sites during 1989. Analyses of population numbers and biomass (cocoons, immatures, and adults) over the 1984-1989 period show no pattern of change relative to energization of the NRTF-Republic.

Litter Decomposition. Litter decomposition provides an estimate of the overall functioning of all soil biota involved in organic matter breakdown and nutrient release. This system level response complements the faunal parameters under investigation and provides a context to evaluate effects seen at the populational and organismal levels of organization.

Estimates of litter decay rates were obtained by examination of mass loss from leaves of known initial weight. Samples of dried maple litter were weighed and placed in mesh netting on the soil surface at both study sites. At intervals throughout the year, samples were retrieved, dried, and weighed. Correction for soil contamination was determined by combusting ground samples and weighing the residue. Analysis of samples taken over the period May 1986 through September 1987 showed no significant differences between sites in litter mass loss. A litterbag series implemented in November 1988, and sampled throughout 1989, showed significantly greater mass loss at the treatment site than at the control for October and November periods. There were no significant differences between years at the treatment site; however, decomposition was greater in 1986 than in 1989 at the control site. Results at the control site are thought to be an indirect result of moisture conditions there.

Litter inputs were determined by collection of leaves in litter traps located at each site. Traps were emptied weekly during the time of greatest leaf fall and monthly at other times. Samples were sorted by category, then oven-dried, cooled, and weighed. In 1989, total litterfall (g/m^2) was insignificantly larger at the treatment site than that at the control site. Previously, total litterfall was significantly greater at the control site. Input values at both sites continue to be consistent with data reported for forests at similar latitudes.

Previous analyses of the amounts of litter on the forest floor (standing crop) showed no significant difference between sites in October, the time of the maximum. The standing crop of litter, however, was significantly higher on the control site during most of the remaining season. In order to

improve these estimates, ashed dry weight for available samples (1987-1989) was determined. Analyses of variance showed that for dry weight estimates, site differences were not significant, nor were there site/date or site/date/year interactions. These results indicate similar patterns of input and decomposition at both sites. Significant within-site variability was found; therefore, the distribution of litter on the sites will be examined as a factor for interpreting the results of future analyses. Significant differences were also found between years. The seasonal pattern of standing crop during 1989 did not show any marked changes with the onset of full power testing and was quite similar to the patterns recorded during 1987 and 1988. Based on maximal standing crop and total litter inputs, the estimated litter turnover time is about one year at both sites.

2.5 NATIVE BEES

Enervated cells containing iron granules have been found in the abdominal segments of foraging honeybees. It has been speculated that these iron structures may play a role in orientation and may provide a basis for the sensing of EM fields by bees. Behavioral changes such as increased dispersal, increased levels of activity, lowered overwintering survival, and modification of nest structure have been described as effects from fluctuations in the earth's magnetic field and from exposure to the EM environment associated with transmission lines.

Honeybees are rare in the forested areas in which the ELF Communications System is located. Native bees, however, are abundant and are of particular importance to ecological communities in the area as pollinators of the resident flowering plants. Native bees have coevolved with resident plants and are able to overwinter in the study area. For these reasons, native bees, rather than honeybees, are being studied. Aspects of nesting activity, nest architecture, and the mortality of native bees have been monitored for possible EM effects from the operation of the ELF Communications System.

Observations on native bees have been made at two treatment sites and two control sites since 1983. Data on nesting activity were collected by direct observation as bees were constructing their nests. Information on nest architecture and mortality were collected using trap nest techniques. This technique involves setting predrilled blocks of wood on shelved hutches and allowing bees to construct nests.

Each nest consists of a series of reproductive (cell) and nonreproductive (basal and vestibular) spaces within the bore of the hole. Each cell is lined with elongate leaves and is provisioned with pollen. After an egg is deposited, the open end of the cell is closed by a partition consisting of rounded leaves. The ends of the nonreproductive spaces are also closed with a series of plugs using rounded leaves and other material. Generally, the egg hatches and the larva molts through a series of stages to overwinter as a prepupa.

Over 40 species of native bees are known to occur in the ELF Communications System area, 20 of which will use trap nests. This study focuses on two abundant species, *Megachile inermis* and *M. relativa*.

Nesting Activity. Disorientation and agitation have been reported for honeybees foraging or building nests near transmission lines. This element examines for similar behaviors by observing the duration of foraging trips made by native bees.

From 1983 through 1986, an extensive effort was put forth in observing, recording, and determining the activity patterns of various species of native bees. Analyses showed that the duration of trips for nest material to cap cells (round leaves) was relatively short and less variable than other foraging behaviors, such as pollen collection. Because *M. inermis* was relatively more active and easier to identify than other species, its leaf foraging behavior was selected for further study as a possible indicator of disorientation or agitation.

In 1989, as in 1983-1988, foraging was faster on control sites (19.5 seconds) than on treatment sites (21.7 seconds). Nevertheless, there was no statistically significant difference between sites in these durations. The average duration of a foraging trip at the treatment and control sites in 1988 was 27 and 20 seconds, respectively. Since the NRTF-Republic was energized at full power during most of the 1989 studies, these preliminary results indicate no adverse ELF System effects on bee orientation.

Sample sizes similar to those obtained in 1987-1989 should be sufficient to detect a statistically significant increase from 21.7 to 41 seconds at the treatment sites 90 percent of the time. This magnitude of change (1.9 times) is within the observed range of foraging durations and is considered reasonable if bees are indeed disoriented.

Nest Architecture and Orientation. When honeybees were exposed to EM fields produced by high-voltage transmission lines, their reproductive output was lowered, and they increased the amount of propolis at their nest entrance. Other reports indicate that under certain conditions honeybees may use the earth's magnetic field to orient their comb. If native bees respond to the EM fields produced by the ELF Communications System, they may alter architectural aspects of their nests in such a manner as to become less competitive than bees exposed to markedly lower EM intensities. In order to examine for this possibility, researchers are monitoring the size, number, linings, cap thickness, and orientation of cells produced by *M. inermis* and/or *M. relativa*.

General linear modeling of 1985-1988 data showed no significant differences between sites or years in the length of nest cells produced by *M. inermis* or *M. relativa*. These analyses were also used to identify other factors that affect the variability of cell lengths--namely, observer, sex of encased bee, and the number of cells per nest. Based on the data collected to date, researchers calculate that they can

can detect a statistically significant difference of at least 1.0 mm (9 percent of the mean) between cell lengths at treatment and control sites 90 percent of the time.

Categorical modeling of 1985-1988 data for the number of cells per nest showed significant differences between sites and years for *M. relativa*. Within-site differences in the number of cells was greater than between-site differences. Differences between years appears to be related to drought conditions experienced during 1986 and 1988. Because of the high variability of cells per nest for *M. relativa*, only marked differences can be detected. However, as the number of cells per nest is easily determined while making other architectural observations, researchers will continue to monitor this variable. There were no significant differences between sites or years in the number of cells per nest for *M. inermis*.

During 1989, ELF researchers continued to collect information on nest plugs and, at the time of reporting, were examining various methods for analyzing these data.

The number of elongate leaves used to construct cells has been examined to determine if bees pad cells with extra leaves when exposed to ELF System EM fields. Analysis of 1985-1988 data collected for *M. inermis* shows no significant differences between sites in the mean number of leaves per cell. If ELF EM fields affect this parameter, researchers are 90 percent confident that they can detect a 15% difference in the current mean of 11.8 leaves per cell.

Since honeybees may use the earth's magnetic field to orient their comb, fluctuating ELF magnetic fields could disturb any preference that native bees have in orienting their nests. Analyses of variance for data collected over the 1985-1988 period, however, show no significant difference between sites or years in the orientation of nests constructed by *M. relativa* or *M. inermis*. Because these data are highly variable, only large differences can be detectable for this characteristic.

Results to date suggest that intermittent operation of the NRTF-Republic at less than full power has had no effect on the nest architecture of bees.

Emergence and Mortality. High voltage transmission lines have been reported to lower the overwintering survival of honeybee colonies. In order to monitor for a possible similar effect on native bees, researchers are examining the proportion of nest cells that produce adults and the sources of mortality at treatment and control sites.

Completed nests were allowed to overwinter at study sites. During the spring, the nests were removed from the sites and taken to a laboratory where they were split open. After data on nest architecture were recorded, cells were placed in individual plastic culture tubes. Tubes and cells were then kept outdoors at ambient temperature until emergence. Date of emergence, species, and sex of offspring were then recorded. Adults were released at the sites where their nest had been constructed

the previous summer. Cells that showed no signs of emergence were opened, and the contents were examined to determine the condition of the bee.

Prior to their emergence in late spring, native bees are subject to mortality during any of several developmental stages (egg, larva, prepupa, pupa, or adult). Failure to emerge is used as an indication of morbidity, and the time of occurrence is associated with the easily identified developmental stage. Pre-overwintering mortality is related to the egg and larval stages, and overwintering mortality to the prepupal and later stages.

Analysis of 1985-1987 data shows that mortality is greater in the pre-overwintering stage than in the overwintering stage. Because the differences between years and sites in the mortality of pre-overwintering stages were large and because the prepupal stage has the longest duration of EM exposure, the proportion of mortality in the prepupal stage has been selected for further hypothesis testing. One confounding factor of this approach is the inability to distinguish between the prepupal stages of bees and those of a wasp parasite. Since both wasp and bee receive the same EM exposure, analyses were performed on combined bee and parasite data.

Analyses of variance showed no differences between sites in prepupal mortality of *M. inermis* (plus parasite) nor *M. relativa* (plus parasite). There were significant differences between years in this variable for both species. Although minimum detectable differences in prepupal mortality have not yet been calculated, it was estimated that a threefold increase in prepupal mortality could be detected, should ELF EM fields alter overwintering survival.

Other analyses showed that those overwintering nests (1988-1989) of *M. inermis* that were oriented in a north/south direction had significantly lower prepupal mortality on treatment sites than on control sites. Nests oriented in an east/west direction had similar mortality at all sites. There were no significant interactions between mortality and orientation in *M. relativa* over the same 1988-1989 period.

2.6 SMALL MAMMALS AND NESTING BIRDS

Some laboratory studies performed at ELF frequencies have indicated effects on small vertebrates; however, the applicability of these findings to vertebrates exposed to EM fields from operation of the ELF Communications System is controversial. In order to address this concern, important biological and ecological characteristics of small bird and mammal species residing in the ELF System area have been monitored by researchers from Michigan State University (MSU).

In the past, both community and populational aspects of resident mammals were monitored. High variability in results and budgetary constraints caused these studies to be discontinued at the end of the 1988 season. However, the community and population characteristics of birds have been monitored by other investigators from the University of Minnesota-Duluth (UMD) since 1984 (see

Section 2.7). This MSU study continues to examine individual aspects of select mammal and bird species, including reproductive, developmental, and physiological characteristics.

Those species selected for studies of most individual attributes are the deermouse, chipmunk, and tree swallow. The black-capped chickadee is also being examined but solely for physiological variables. The project uses five treatment sites in, or immediately adjacent to, the antenna ROW and four control sites with habitats similar to the treatment sites. Areas on the control sites have been cleared (sham ROWs) and are being treated the same as the antenna ROW.

Embryonic Development. Prenatal developmental stages have been shown to be particularly sensitive to many types of environmental perturbations. Although different from the fields produced by the ELF System, some EM fields have been reported to have a direct effect on embryonic development. Indirect effects on development may be also possible, should EM exposure affect parenting behavior. Possible EM effects to prenatal development are being monitored using the incidence of abnormalities for embryos of tree swallows nesting near the ELF Communications System. (The prenatal development of mammals is not being studied because of probable adverse effects to local population levels by the sacrifice of reproductive females.)

Embryos of tree swallows were collected at three treatment and two control study sites after four days of incubation. The embryos were dissected from the egg, preserved, and then examined microscopically. Each egg was coded so that the investigator who examined for abnormalities was unaware of the source site. The following were checked for abnormalities: head, heart, branchial arches, spinal cord and somites, limb buds, allantois, and amnion, as well as the flexion and rotation of the embryo.

Several types of abnormalities were identified, including lack of development, chaotic development, rotation reversals, spine abnormalities, allantois reversals, and posterior directed allantois. The incidence of these abnormalities during 1989 was about 14 percent (all sites). The incidence of abnormalities occurring in the ELF System area is consistent with the frequency of tree swallow hatch failures reported in the open literature (15-20 percent). Chi-square analysis showed no significant differences in the incidence of abnormalities between embryos collected at treatment and control sites during 1989.

Since avian embryos must develop in a closed system, the resources allocated to each offspring during oogenesis could have a marked influence in determining chick survival. To determine whether operation of the ELF System adversely affects the amount of nutrient deposited, each egg was weighed and measured at the time of collection. Calculated egg volumes were similar to measured weights, therefore, volumes were used in further analyses. There were no significant differences in the mean volume of eggs collected during 1989 at treatment and control sites.

Fecundity, Growth, and Maturation: Tree Swallows. The purpose of this element is to monitor important aspects of the reproductive and postnatal growth processes in swallows. Variables are numbers of eggs per clutch, hatching success within clutches, rates of postnatal growth, development of hatchlings, and nestling mortality.

Studies are carried out in clearings where arrays of nest boxes have been erected. The boxes can be opened to permit observations and measurements of the young. Active nests are checked daily or every other day to determine the dates that eggs are laid, the number of eggs, hatching dates, and overall hatching success. Monitoring of the nests for nestling growth and mortality then continues until all young fledge. Attempts to monitor parental attentiveness to nestlings using video recording devices, and most recently temperature probes, have proved to be too variable and costly. Monitoring of this parameter was discontinued at the end of the 1988 field season.

Clutch size (maximum number of eggs laid in a nest) has been used as an indicator of fecundity. As in prior years, there were no significant differences between study sites in mean clutch size. Mean clutch size in 1989 was 5.1 and 5.4 eggs per nest at treatment and control sites, respectively. Analyses of data pooled over the last five years show no significant differences between sites or years; no plot/year interactions were noted. Researchers continue to collect and analyze data on available food supply (insect biomass) as one possible factor influencing clutch size.

Average egg temperature during incubation has been used as an indicator of parental attentiveness to eggs, but budgetary constraints stopped further monitoring of this variable. Previous analyses of 1987 and 1988 data failed to indicate any significant differences between sites in mean egg temperature during the course of incubation.

Hatching success during 1989 was 83.3 percent at the treatment and 83.4 percent at the control sites; this slight difference was not statistically significant. According to analysis of data pooled over the 1985-1988 period, the likelihood to hatch was independent of both site and year. The actual number of birds to hatch in 1989 was greater on the treatment site (4.3 young/nest) than on the control site (4.2 young/nest). Analysis of variance of hatch frequency data for the last five years shows significant differences between years but not between sites.

No significant difference between sites was found during 1989 in the postnatal growth indicators of mean number of days to eye opening or feather eruption. In 1989, the mean number of days to eye opening was 8.6 days at treatment sites and 7.8 days at control sites; the mean number of days to feather eruption was 9.1 days at treatment sites and 9.6 days at control sites. Both eye opening and feather eruption took longer in 1989 than in 1988. Data pooled over the 1986-1989 period showed significant differences between nests, but none between sites, for these two developmental parameters.

In order to examine growth rates, periodically measured values were fit to models. Body weight, tarsus length, and ulna length data (1985-1988) best fit logistic models, whereas wing length data best fit an exponential model. The models were used to produce parameters (e.g., growth rate constants or rate of growth at the inflection point) that were then examined by nested analysis of variance. For weight, ulna, and wing growth constants, no significant differences between sites were detected for 1989 or previous years. Except for wing length (which does not have an inflection point), weight, ulna, and tarsus inflection points were not significantly different between sites. The tarsal growth constant, however, was significantly larger in 1989 for birds on the treatment site than for birds on the control site. Because a new protocol was used to analyze tarsal growth in 1989, the importance of a site difference in this parameter awaits further examination of previous data using the new protocol.

In 1989 fledging success was greater at control sites (22 percent) than at treatment sites (18 percent); however, this difference was not statistically significant. The percent of success for fledging was markedly lower in 1989 than in 1988 when the success was 85 percent at the treatment and 69 percent at the control sites. The actual numbers of young to fledge per nest during 1988 were 0.8 and 0.9 at treatment and control sites, respectively. These numbers are down from 1988 values, which were 4.3 and 3.3, respectively. Data for fledging success and numbers of young to fledge, pooled over the period 1985-1989, show significant differences between years but not between sites.

Values obtained in these studies of fledging success, hatching success, and clutch size are similar to those reported in the literature for other studies of tree swallows. The overall mortality of eggs and nestlings and the failures of entire nests during 1989 were not significantly different between treatment and control sites. The relatively high mortality observed during 1989 can be attributed to abandonment of nests during a cool June period when newly hatched young and unhatched eggs required incubation.

Fecundity, Growth, and Maturation: Deermice. The purpose of this element is to monitor important aspects of the reproductive and growth processes in deermice. Rates of postnatal growth and development of nestlings were examined during 1989. Previously maternal attentiveness to nestlings, number of young born per litter, and the proportion of young surviving until weaning were also monitored. Although initial litter sizes and subsequent mortality were apparently recorded during 1989, no data or analyses were formally reported by the researchers. Monitoring of maternal attentiveness was stopped at the end of 1988 due to the high variability of this characteristic.

Large, open enclosures were used to restrict the movements of deermice during studies of postnatal growth and development. The deermice to be studied were captured in mixed deciduous forests near the enclosure sites. The animals were paired, and when the female was pregnant, she was transferred to the large enclosure to give birth and rear the young to weaning. Observations were then made while the young were located in a nest within the enclosure.

Growth studies to date have shown that growth curves of temporal change in the body mass of nestlings are different between litters. Growth rates, therefore, have been estimated using linear regression analyses for growth of each individual in a litter. Examination of individual growth during 1989 using analysis of variance showed significant differences between litters but not between sites. In 1989, as in previous years, the age at eye opening and the age at incisor eruption were not significantly different between sites.

Homing Studies. Published information suggests that magnetic fields are one of several cues used in the orientation of some birds and mammals. Since animals are able to find food and escape predators more effectively in their home range, any disturbance of the ability to return to, or use, a home range could decrease an animal's probability of survival. Monitoring of the homing ability of tree swallows and deermice is in progress, therefore, to assess for possible effects from the operation of the ELF Communications System. The variables being examined are the likelihood to return (number of displaced individuals that return home) and, with swallows, the amount of time taken to return home.

Adult birds from treatment and control sites were captured at nest boxes while brooding their young. Captured birds were banded, color-marked, and taken to release sites. (Release sites are located in open areas 30 km from the capture site.) The direction of the release points from the nest sites requires those birds returning to treatment sites to cross both east-west antenna elements of the NRTF-Republic. Birds taken from a single control site are displaced at an angle and distance similar to that used for birds taken from the treatment sites, but do not cross or come near any of the antenna elements. Observers located near the nest boxes record the times at which the displaced birds return. Previous studies have shown no significant differences between genders or directions of displacement.

With the exception of one bird captured at a control site, all birds displaced during 1989 returned to their nests within 300 minutes. Mean time to return was not significantly different for birds captured at two treatment sites; therefore, the data for both treatment sites were pooled to compare with return times for birds captured at the control site. As for the previous three years, the mean time to return to treatment sites during 1989 was significantly less than return times to the control site. Since 1987, displaced birds have consistently returned to treatment sites about 50 minutes faster than birds returning to the control site. The cause for the difference in return times has not been determinable.

Chipmunks and deermice were captured on a trapping grid at treatment and control sites. Displacements took place during, or just prior to, the next activity period following capture; deermice were displaced at dusk and chipmunks in the morning. Individuals were displaced either to the south or west of the trapping grid, with each animal displaced 450 m from the trap at which it was captured. The displacements to the south were through relatively continuous forest, whereas displacements to the west required the returning animals to cross the antenna ROW or sham ROW. Once an animal was displaced, traps on the grid were checked morning and evening for the next five days.

Since there was no significant difference between west or south displaced animals in their likelihood to return, all data for each site were pooled for intersite comparisons. For deermice the likelihood to return during 1989 was significantly greater at the treatment site. Analyses of all data collected during the 1986-1989 period show no significant differences between sites or years. For chipmunks displaced during 1989, there were no significant differences between sites in the likelihood to return. Analyses of data collected over 1986-1987, however, show significant differences between sites and years. The likelihood of return for chipmunks is slightly greater at the treatment site than at the control site with rates of return larger in 1989 and 1986 than in 1987 or 1988.

Physiology: Peak Aerobic Metabolism. The purpose of this element is to determine the peak aerobic metabolism of chickadees and deermice during an annual period of severe stress (winter). This variable provides a general index of an animal's health.

Black-capped chickadees and deermice were collected during the winter along the ELF Communications System's ROW and at a control site. Animals to be tested were held at an outdoor facility with food and water provided ad libitum. Tests for peak metabolism were performed in an ethanol-cooled chamber using a version of the helium-oxygen method. Test equipment was located at a laboratory in Crystal Falls, Michigan; the holding facility was situated several miles south of the city. Studies have shown that the peak metabolic rates of deermice and chickadees do not change during three weeks of holding in the outdoor cages. After testing, animals were released at their collection site.

Previous analyses of data pooled over the period 1986-1988 indicated no significant differences between sites or between years for deermouse metabolic rates. However, similar analyses showed these rates for birds captured on control plots to be slightly, but significantly, higher (4 percent) than for birds captured on treatment plots. There were no significant differences between years or year-site interactions. It was concluded that in the years prior to full operation of the NRTF-Republic (1986-1988) peak metabolic rates were stable for deermice and chickadees from year to year, similar at both treatment and control sites for deermice, but somewhat different between sites for chickadees. Single-factor analysis of covariance showed no significant differences between sites in the peak (weight specific) metabolic rate for deermice or chickadees examined during 1989.

2.7 BIRD SPECIES AND COMMUNITIES

Birds are sensitive to magnetic fields and use such cues, along with others, for orientation. To examine for possible adverse effects from EM fields produced by the ELF Communications System, species and community characteristics of birds that migrate and breed in areas adjacent to ELF transmitting facilities have been monitored.

A (variable width) line transect method is used to census the bird community. Study sites consist of 10 transects (five treatment and five control) in Wisconsin and 10 transects in Michigan. Treatment transects are parallel to and about 125 m from the edge of the antenna ROW. Control transects are variously oriented and generally at distances greater than 10 km from the antenna. For analytical purposes each transect is subdivided into eight segments. Observers walk along a randomly designated transect to determine bird species and numbers from sightings or bird songs. To properly qualify the collected data, habitat structure on treatment and control transects, possible "edge effects" caused by the antenna ROW, and variability due to differences between observers have been examined.

Since 1986, the identification and enumeration of bird species has been performed during each of five periods throughout the year: spring migration (May), early breeding (June), late breeding (July), early fall migration (August), and late fall migration (September). Collection of data near the NRTF-Clam Lake was completed during 1989. To enable comparisons of conditions during preoperational/ operational periods of NRTF-Republic operation, however, the collection of bird abundance data in Michigan will continue through 1991.

Parameters selected for statistical analyses include: species richness, total number of birds, number of individuals for abundant species, number of individuals for common species, and number of individuals within select guilds. To date, no consistent pattern has emerged to demonstrate that birds are more or less plentiful on treatment compared to control segments in either state. Few significant differences have been found at the community or species level, and significant differences in one season or year have generally not been repeated in subsequent years or seasons.

The following summary emphasizes 1989 research activities and findings for studies in both Michigan and Wisconsin.

<u>Number of Individuals and Species Richness.</u> In 1989, the mean number of individual birds per transect segment was highest during May and June in Wisconsin, and during June and July in Michigan. Analyses of variance showed no significant differences between study sites in the mean number of birds per transect segment in Wisconsin or Michigan. Wisconsin data were also examined further by using t-tests to compare the mean number of birds observed on segment pairs that were matched for their vegetational similarities. According to the t-tests, the mean number of birds was significantly greater on treatment segments during July. No significant differences between treatment and control segments were found for the other four 1989 periods.

The mean number of species per segment was highly correlated to number of individual birds and, except for t-tests of Wisconsin data, had the same statistical results as bird numbers. Those t-tests showed no significant differences between treatment and control segments for any of the 1989 sampling periods.

Bird numbers and species have experienced an overall decline in both Michigan and Wisconsin since 1985. Analyses of variance indicate significant interyear differences in these bird community characteristics for each of the five annual sampling periods. Although ELF researchers generally perform their counts during the same calendar period each year, they have noted differences between years in weather conditions at the time of sampling. Because weather conditions may confound interyear comparisons, researchers are continuing to examine this aspect with an emphasis on the relationship of precipitation to community characteristics.

At present, treatment and control comparisons appear to be the most reliable for examination of possible effects from operation of the ELF Communications System. No consistent pattern that demonstrates an effect from ELF System operation on the number of bird species or individuals has emerged in either Wisconsin or Michigan.

Abundant and Common Species. Possible EM exposure effects may not influence all bird species in the same manner. If, as a result, some species are more plentiful in control areas and other species are more plentiful in treatment areas, such differences may cancel, producing nonsignificant results in bird community parameters. Possible effects to individual species that are abundant and common at the study sites, therefore, are also under study. Those species with a mean of more than one individual per transect segment in control or treatment areas of either state in any season are considered as abundant. A second group, common species, was chosen based on a lower frequency of occurrence than abundant species.

The most plentiful species present on treatment and control segments varied among seasons and between states. When all sampling periods were considered, particularly abundant species present on study transects during 1989 included the Nashville warbler, ovenbird, white-throated sparrow, red-eyed vireo, black-capped chickadee, golden-crowned kinglet, and hermit thrush. Among these and other abundant species, 5 of 34 comparisons (using ANOVA) showed a significant difference between treatment and control segments in Michigan; 4 of the 5 comparisons indicated a greater number of individuals for a given species on control segments. In Wisconsin, 6 of 31 comparisons indicated a significant difference between segments; 4 of the 6 had a greater number of individuals on control segments. In t-tests of vegetation-matched, Wisconsin segments, significant differences were found between treatment and control segments in 2 of 31 comparisons involving abundant species; in both significant cases the number of individuals was greater on the treatment transects.

Unlike abundant species, common species were examined using prominence values. Prominence values weight both the frequency of occurrence and the number of individuals. In this case, prominence values were considered preferable to using either total number of individuals or number of segments on which a species was observed in examining for differences between treatment and control areas. In Michigan, 18 of 105 comparisons of prominence values showed significant differences

between treatment and control segments; 9 of the 18 significant differences were higher on the control segments. In Wisconsin, the prominence values for 20 of 100 intersite comparisons were significant; 14 of the 20 comparisons had higher prominence values at treatment sites than at control segments.

During 1989, as in the past, the number of significant differences between treatment and control areas in the number of individuals (common and abundant species) or their prominence values was relatively small (17%). The occurrence of significantly greater numbers of individuals or their prominence values continued to be nearly equally distributed between treatment (28) and control (23) segments. Over the term of the study, only a few species have been found to be consistently and significantly more plentiful on either treatment or control segments among seasons within a year or within seasons between years.

Guild Analysis. In monitoring for possible effects to birds from the ELF Communications System, it is important to determine whether significant findings are related to EM exposure or to habitat differences between treatment and control sites. In addition, the possibility that effects found to be significant for some species also affect other species with similar preferences may need to be explored. These concerns are being addressed by guild analyses. Species that belong to the same guild share important biological characteristics, such as food or habitat preferences.

All species of birds found on study sites have been classified into guilds on the basis of foraging location and preferred breeding habitat. The total number of individuals for each guild type on treatment and control transect segments were then compared for the 1989 season. Results showed few significant differences between treatment and control segments in the number of individuals from foraging guilds (4 of 50 comparisons), but more significant differences in the number of individuals from habitat guilds (14 of 60 comparisons). These results are nearly identical to 1988 findings.

Vegetation assessments performed during 1986 and 1987 have shown, in both states, more coniferous and early successional habitat on treatment segments and more deciduous habitat on control segments. During 1989, the mean number of birds showing significant differences and preferring coniferous and early successional habitats was larger on treatment segments. The number of birds showing significant differences and preferring deciduous habitats was larger on control segments. These results strongly support the contention that habitat differences are responsible for the distribution of those abundant and common species of birds showing consistent and significant differences between sites.

2.8 AQUATIC BIOTA

Aquatic biota, particularly fish, have been shown to use, or react to, weak ELF EM fields. The purpose of this study is to monitor a riverine ecosystem for possible effects to aquatic biota from long-term exposure to the low-level EM fields produced by the ELF Communications System in Michigan. Populational aspects as well as the functional and structural components of three major aquatic communities (i.e., periphyton, aquatic insects, and fish) are examined.

Two similar sections of the Ford River are used as matched study sites. One site is located adjacent to the north-south leg of the NRTF-Republic (treatment); the other is located more than 10 km downstream (control). No major tributary exists between the sites. At each site ambient environmental factors are monitored and ecological experiments occupy adjacent stream segments. Four additional netting sites are located upstream of the control site in order to determine the migration pattern of fish.

2.8.1 Periphyton

Periphyton are a community of microscopic plants and animals associated with the surfaces of submerged objects. Unlike organisms suspended in the water column, the structural and functional aspects of the periphyton community at a given location are governed by conditions at that point. Because they show responses immediately at the source of a perturbation, periphyton are being used to assess for possible changes in the aquatic community due to the operation of the ELF Communications System.

Since the periphyton community is dominated by diatoms, they are emphasized in monitoring of structural aspects; however, functional aspects such as chlorophyll, biomass, photosynthesis, and respiration are determined for the entire community (i.e., diatoms, plants other than diatoms, and animals). Quantitative determinations are made by collection of periphyton colonizing artificial substrates of known surface area. Preliminary studies in the Ford River have shown that the periphyton established on glass slides were representative of the periphyton community found on natural substrates.

Statistical comparisons between sites used the paired t-test; however, "before and after, control and impact site" (BACI) techniques were emphasized in most analyses. The BACI technique compared the mean of the "before" differences between control and impact (treatment) sites to the mean of the "after" differences between sites by using an unpaired t-test. For preliminary statistical analyses, samples collected from June 1983 through April 1986 are considered "before" data and samples collected from May 1986 through September 1989 are considered "after" data. (Low current testing was initiated at the NRTF-Republic during July 1986.) To construct a complete picture of relationships, researchers have calculated a correlation matrix for all ambient and biological/ecological variables and have also determined minimum detectable differences (MDDs).

Structural Aspects. The purpose of this element is to monitor select variables of the diatom component of the periphyton community. Indices for species diversity, evenness, and abundance allow the detection of subtle shifts in the community's makeup; total cell density and biovolume of diatoms give an indication of any overall change in the dominant biota of the community.

Glass slides emplaced at study sites for 28 days were used to identify and enumerate colonizing diatoms. The community that develops on emplaced slides most often consists of 50 to 70 species of diatoms. Because diatoms vary greatly in their size distribution, the number of individuals (total cell density) alone does not give an adequate picture of the community's makeup. Therefore, cell volume measurements for the dominant diatoms were also determined. Volume estimates were multiplied by the density of each species and summed to provide an estimate of the total biovolume for all cells present.

Since 1983, the seasonal pattern has continued to be high diversity and evenness during winter, with lower values in summer. Paired t-tests of species diversity and evenness failed to show a significant difference between sites during 1988-1989, or for data pooled over the 1983-1989 period. BACI comparisons, however, did show a significant difference between before and after data. Further analyses showed no significant differences between years when pooled and examined on a seasonal basis (winter or summer) and only a few differences when individual years were compared. For whole-year data, MDDs were 7 percent for diversity and 5 percent for evenness. The fact that most interyear comparisons did not support overall BACI results and the absence of differences between 1989 (maximum EM exposure to date) and other years suggest that the interyear differences in diversity and evenness result from some factor other than operation of the ELF System.

The seasonal pattern for the density of diatoms continues to be lower densities during the winter than during the summer. Peak diatom density usually occurred within a four-month spring-summer period. The time and duration of the peak was found to be highly variable between years. Paired t-tests of density showed no significant differences between sites for 1989 or data pooled over the 1983-1989 period. BACI comparisons did show significant differences between "before and after" data (MDD, 59 percent). The high density of diatoms occurring after April 1986 may be due to factors associated with the extremely dry conditions experienced each May and early summer of the 1986-1989 period. Diatom cell density has been shown to be significantly correlated with water temperature.

Comparisons of individual cell volumes of dominant diatom species failed to show significant differences between sites for 1988-1989 or for data pooled across years (1983-1989). BACI comparisons showed no significant difference between before and after years, either on a whole year (MDD, 21 percent) or on a seasonal (MDD, 30 percent) basis. Ambient water temperature or concentration of dissolved oxygen accounts for 54 to 96 percent of the variance in cell volumes.

Total biovolume (cell volume times density) of dominant diatom species did not show significant differences between sites for 1988-1989 or for data pooled across years. BACI analyses indicated a significant difference between before and after years (MDD, 53 percent). Site differences before and after energization of the antenna are attributed to ambient conditions. The concentration of silicate in the water accounts for 72 to 100 percent of the variability in whole-year biovolume values.

Functional Aspects. Because numbers or types of diatoms alone do not provide a complete characterization of the periphyton community, the purpose of this element is to monitor such aspects as chlorophyll a, organic matter accumulation, photosynthesis, and respiration, all of which represent the functioning of the entire community.

Slides were emplaced in the Ford River for 14 days for determinations of accrual rates and 28 days for determinations of standing crop estimates of chlorophyll a, phaeophytin a, and organic matter biomass. Fluorometric methods were used for analyses of chlorophyll and phaeophytin. Organic matter biomass was determined using changes in ash-free dry weight per unit area.

Annual patterns for chlorophyll a standing crop and accrual continued to remain similar between sites and years. The annual pattern was one of winter lows, with a peak value occurring in July or August. Considerable year-to-year variability in both standing crop and accrual rates did occur, however, due to the presence (or absence) of secondary peaks (March through June) and/or the magnitude of the summer peak. Secondary peaks occur when spring conditions are dry (i.e., having low stream flows and relatively warm temperatures such as experienced over the 1986-1989 period). BACI analyses did show significant differences between "before and after" comparisons of standing crop and accrual rates (MDD, 29 percent). These results are thought to be related to climatic conditions and not EM exposure.

Organic matter standing crop and organic matter accrual rates showed the same annual pattern as chlorophyll. Paired t-tests examining site differences showed the same results as chlorophyll a; however, BACI analyses of data on organic matter standing crop showed no significant difference between before and after periods (MDD, 28 percent). Like chlorophyll a, organic matter standing crop was significantly correlated with temperature and discharge.

Changes in dissolved oxygen concentrations in light/dark chambers with periphyton-covered substrates were used to estimate community productivity and respiration. Gross and net primary production as well as respiration values were very similar between sites. Gross primary production rates (1984-1989) showed no significant differences between sites for data pooled for before and after comparisons or for individual year-to-year comparisons.

2.8.2 Aquatic Insects

As part of the integrated studies of the aquatic ecosystem, insects are being monitored as representative of the primary and secondary consumer levels in the aquatic food chain. These studies examine the important functional insect groups, such as shredders, collectors, predators, and grazers. Both community and individual aspects of organization are being monitored. The community aspects are leaf litter processing; insect colonization patterns on leaf litter and artificial substrates; and structural descriptors of community change such as species richness, individual abundance, and species diversity. The monitoring of individual aspects emphasizes changes in individual behavior such as alterations in movement patterns and feeding activity.

Feeding Activity of Grazers. The movement of energy from producer (periphyton) to higher trophic levels is important in maintaining the aquatic community. The relationship of a grazing insect on the periphyton community is being monitored to determine possible effects from the ELF System on energy transfer.

The study approach uses streamside chambers to which are added tiles precolonized with periphyton and grazing insects. The chambers are subdivided so as to allow the introduction of different numbers of grazers (0 to 30) per experimental run. After a period of time the tiles are removed, and the periphyton are analyzed for chlorophyll a, organic matter biomass, and diatom cell counts. Development of data collection techniques began in 1985 and continued into 1989. Final identification and enumeration of diatom species collected during 1989 will be completed during 1990.

Preliminary studies have shown that a grazing insect can change the composition of the periphyton community at grazer and diatom densities found naturally in the Ford River. Grazing, however, does not affect all community parameters (e.g., chlorophyll a, or biomass), and its effects are not consistent. Studies performed in 1985 and 1986 showed that grazing affected the abundance of major species; yet in 1987 there were no measurable changes between grazed and ungrazed tiles; and abundance changes for major species in 1988 were opposite those determined in 1985 and 1986.

Researchers attributed the lack of effects between grazed and ungrazed tiles to short exposure times and siltation problems encountered during the course of the studies. Monitoring experiments performed during 1989 were longer (14 days) than previous studies (7 days), and siltation problems (1987 and 1988) were not encountered. Completion of 1989 grazing data analyses is anticipated during early 1990.

Benthic Insect Community. Studies of possible EM effects on aquatic insects cannot be found in the literature; however, effects of high-intensity EM ELF fields on the behavior of terrestrial insects has been documented. It has also been reported that some aquatic biota use weak EM fields to locate prey or orient themselves. Benthic insects being major organisms in the primary and secondary trophic

levels of the Ford River, their community structure and function is being monitored for possible effects from operation of the ELF Communications System.

Riverine substrates contained in sample baskets were emplaced at study sites for one-month periods at intervals throughout the spring, fall, and summer seasons. Insects were collected from the substrates, identified, and counted. Numbers of individuals, diversity, richness, evenness, and percent numerical dominance for selected species were determined for each replicate. Total sample biomass and biomass for functional feeding groups were determined. For those insects with high numerical abundance, mean dry weight per individual was also computed.

Analyses of variance showed the treatment site to have significantly larger numbers of individuals and a greater diversity of species than the control site. The control site had significantly fewer species with a more uneven distribution of individuals among species compared to the number of species and individuals at the treatment site. Several physical factors, particularly riverbed heterogeneity, are thought to be responsible for the differences between sites. In addition to site differences, significant differences between years (1983-1988) and within years for these structural community parameters were evident. Graphs of all structural parameters failed to show any pattern related to energization of the NRTF-Republic. Previous analyses have demonstrated a positive correlation between water temperature and both diversity and number of species. In addition, cumulative data show water temperatures at the treatment site to be warmer than those at the control site.

Analyses of variance displayed significant differences between sites, years (1983-1988), and months within years (April-November) for total insect biomass. Graphic presentations showed higher overall insect biomass at the treatment site than at the control site. When total biomass was analyzed according to seasons, no site or year differences appeared for the spring and summer periods. Total biomass during the fall was significantly different between both years and sites. The annual pattern of insect biomass at both study sites was maximal quantities during spring and summer and minimal values during the fall. Insect biomass was positively correlated with diatom density and water temperature, and negatively correlated with stream discharge.

Total biomass values were partitioned into functional feeding groups including: collector-gatherers, collector-filter feeders, shredders, and predators. As predators contributed more to the total biomass than the other feeding groups, their relationship to potential prey was further analyzed. Arcsin transformed predator/prey ratios were examined using analysis of variance. Significant differences between sites, years (1984-1988), and months within years were determined by a three-way analysis of variance of the ratios. Over the 1984-1988 period, 1986 was unique in terms of low rainfall, moderate fall temperatures, and a markedly high predator/prey ratio at the treatment site. Reanalysis of predator/prey ratios by season, and excluding 1986 data, showed no significant differences between sites or site/year interactions for the summer and fall seasons.

The relation of water temperature, discharge, and diatom density on insect community parameters will continue to be examined during 1990. BACI analyses and use of cumulative EM exposure are also planned.

Leaf Litter Processing. In headwater streams such as exist in the ELF Communications System area, only a small portion of the energy supply to the ecosystem is provided by aquatic plants and algae. The maintenance of community structure is largely dependent on the input of organic materials (i.e., leaves) from riparian vegetation. Macroinvertebrate consumers, mainly insects, process the leaves, making the leaf biomass available to higher trophic levels (predators).

Processing and insect colonization patterns using "leaf pack" bioassay techniques were used to monitor for possible EM effects to this energy pathway. Leaf processing rates (mass loss) were used to quantify the overall feeding activities of the colonizing community, while species diversity, evenness, and richness were used to characterize colonization patterns. Processing rates were determined for both fresh and autumn-abscised leaves emplaced in the Ford River and retrieved at regular intervals over an 80-day period. Leaf processing rates were computed as decay coefficients and analyzed using Wilcoxin rank sum tests for intersite comparisons. Fresh and autumn leaf data were analyzed separately.

Since initiation of the study, fresh leaves have been processed by aquatic organisms at a faster rate than autumn leaves. Although rates varied between years (1984-1989), there were no significant differences between sites in the rate of processing fresh leaves. Autumn leaves, however, continued to be processed at significantly faster rates at the treatment site than at the control site. Relative differences between the sites in the rate of leaf processing have been similar year to year and therefore continue to be amenable as a parameter for monitoring this community.

Analysis of variance was used to examine structural parameters (taxon diversity, taxon richness, and numbers of individuals) for the communities colonizing fresh and autumn leaf packs. Significant differences occurred between years (1984-1988), but not between sites, in the structure of the community on autumn leaves. Similarly, significant differences existed between years in the structure of the community inhabiting fresh leaf packs. On fresh leaf packs, diversity was significantly larger on treatment sites; however, there were no significant differences between sites in taxon richness or number of individuals. In summary, leaves at the treatment site supported either a similar or more diverse insect community than leaves emplaced at the control site.

Analysis of variance was also used to scrutinize functional community parameters for organisms colonizing fresh and autumn leaf packs. These parameters included total insect biomass (adjusted to leaf biomass), and the mean (dry) weight per individual for three abundant insect species. In general, fresh leaves supported a larger insect biomass than autumn leaves. On fresh leaves, insect biomass was significantly larger at the treatment site than at the control site. Within each site, biomass on fresh

leaves was significantly different between years (1984-1988). Total biomass associated with autumn leaves showed significant differences between years but not between sites. Growth rate patterns the insects were not significantly different between leaf types or sites.

Results to date show neither significant differences between sites nor any pattern relatable to energizat'on of the NRTF-Republic.

Insect Movement Patterns. Other studies have shown high-intensity ELF EM fields can stress terrestrial insects. As aquatic insects often use drift in response to stress conditions, this behavior has been used to monitor for possible effects from the operation of the ELF Communications System.

Mark-and-recapture techniques have been used to discern the movement patterns of displaced dragonfly naiads. Chi-square tests of data collected over the 1985-1989 period showed significant differences between sites and years in the distance that naiads moved after release. The distances traveled by the naiads reflect natural movement patterns, and the high variability in distribution is probably attributable to varying ambient conditions (i.e., river velocity, depth) experienced between experiments. Before the 1990 season, all data will be reanalyzed using unpaired t-tests. If these analyses show no relationship between movement patterns and ELF EM exposure, this element will be discontinued from further study.

2.8.3 Fish

Fish are tertiary consumers feeding on other lower trophic levels. Possible effects at the producer level (diatoms), primary consumer level (grazers, shredders), or secondary consumer level (insect predators, small fish) can be reflected in the community structure of the tertiary consumers. In addition, some species of fish have an ability to perceive extremely small EM fields. Since it has been shown that fish use this perceptive ability to orient themselves and to detect prey, the structure of the fish community and movement characteristics of the mobile fish community are being monitored for possible effects from the operation of the ELF Communications System in Michigan.

Mobile Fish Community. Fyke nets and weirs have been deployed across the width of the Ford River drainage at five sites in or near the ELF Communications System. All fish are collected, and both community characteristics and movement through the area are recorded. Community characteristics recorded are species composition, species abundance, and biomass. The travel time of marked fish through the ELF System area, as well as the condition of abundant fish species, is also examined.

As in 1988, the number of fish species collected during 1989 was higher at the downstream control site (19) than at the treatment site (14). There were no significant differences between sites in the diversity of the mobile fish community, either in 1989 or within any given year over the period 1983-1989. Site differences in the number of species were due to the presence of a few rarely found

species at the control site. Overall, the treatment and control site continued to be similar in species composition.

Numerically, and by biomass, the mobile fish community at treatment and control sites has been dominated by the same five species since 1984. The numbers of common shiners and creek chubs made up the two highest percentages of the catch; the other common species were the burbot, brook trout, and white sucker. The common shiner was the most dominant species at both sites when the 1989 community was analyzed for percent catch by biomass. Despite changes in abundance from year to year, within years there were no significant site differences in percent catch by numbers or in relative abundances by biomass.

The 1989 recapture frequency of nonsalmonid fish at sites other than the marking site was at least 7 percent. Recapture percentages during 1989 were similar to percentages obtained during the 1984-1985 period. The movement of fish through the ELF Communications System area during 1986-1988 was slower than during 1985 to 1989. Slow rates of movement were related to a significantly lower flow rate for the Ford River during the 1986-1988 period than that experienced during other years of the study.

To assess possible direct effects of the ELF Communications System on the mobile fish community, analyses were initiated in 1986 for determining the growth and condition of captured fish. The common shiner, creek chub, white sucker, and northern pike were selected as indicator species for the community. Analysis of data pooled over both sites and over the period 1983-1989 showed that common shiners and creek chubs had average to better-than-average growth in comparison to literature values. White suckers and northern pike displayed poor growth in comparison to literature values.

In addition to growth, the condition of common shiners, creek chubs, and white suckers was examined using relative weight condition factors. As for growth, data were pooled over sites and years (1983-1989). Condition factors for creek chubs and white suckers were below their respective species mean, whereas condition factors for the common shiner were above the species mean for all years examined. Statistical comparisons between sites or years for growth or condition will be reported at a later date.

Brook Trout Movement. The purpose of this element is to monitor for possible effects to an important sportfish, the brook trout. Attributes being monitored include pattern, rate and magnitude of migration, and population aspects such as age, growth, and condition.

The general pattern of trout migration has been an upstream movement in the spring to early summer, with a varied intensity and timing of peak movement from year to year. Peak catch occurred in June during 1984, 1987, 1988, 1989; in July during 1985; and with no peak apparent during 1986. Trout migrate through the ELF Communications System area (control and treatment sites) to the confluence of

the Ford River and Two Mile Creek. Virtually all trout migrate up Two Mile Creek; optimal growth temperatures appear to be responsible for this movement. No downstream movement from Two Mile Creek was observed for sampling periods lasting through November. Factors affecting timing of peak catches and distribution pattern appear to be water temperature, stream velocity, and trout population size.

Brook trout were found to move across the ELF System ROW from the downstream control to Two Mile Creek at rates of 2.9 to 5.0 km/day prior to energization of the NRTF-Republic and at a rate of 4.5 km/day after energization in 1989. Tagged trout were not recaptured in 1986, and only a relatively small number were obtained during the 1987-1989 period. Although movement rate comparisons indicate no gross differences due to energization, no conclusions can be drawn for ELF System effects on movement. Further analyses (Kolmogorov-Smirnov test) of these data emphasizing the number of days it takes individual fish to move from the point of marking to another site are planned.

Age and growth analysis indicated that the brook trout in the Ford River exhibit average or better growth than that reported in the literature. As for the nonsalmonid species, brook trout were examined using relative weight condition factors. Brook trout from the Ford River weighed average to below average when compared to the calculated literature average. Statistical analysis of these data is still in progress, and will be reported in the next annual summary report.

3. ENGINEERING SUPPORT

The relationship between low-level EM exposure and biological response remains unresolved. Beyond EM intensity comparisons (treatment and control, before and after), other EM characteristics of the ELF Communications System may need determining to further interpret the results of the biological studies. For example, EM aspects of potential concern are:

- exposure duration
- duty cycle (power, number of "on/off" powerings)
- interaction with other fields
- wave shape
- phasing between antenna elements.

This is not to say that these aspects will cause biological effects, but only to indicate the need to document various facets of the EM fields generated by the ELF Communications System while the monitoring program is in progress. Because extensive and accurate EM data may be needed to fully evaluate cause-and-effect relationships between EM exposure and biological/ecological end points, IITRI assists university investigators by providing them with engineering support.

The following summarizes the operational characteristics of the ELF System and measurement of EM field exposures at study sites during 1988 and 1989, as well as other engineering activities carried out by IITRI in support of the program during 1989. A more extensive presentation of these topics can be found in Reference 2.

3.1 TRANSMITTER OPERATIONS

This section summarizes the operational characteristics of the transmitting facilities in both Wisconsin and Michigan over the 1988-1989 period.

Data on transmitter operations have been provided to IITRI by the Navy on a minute-by-minute basis, and included all changes in operational frequency, modulation, power, and phasing for each antenna element. This information has been received as graphical and tabular summaries and, when requested, in detailed tabular form.

The NRTF-Clam Lake, Wisconsin, has been fully operational since the last quarter of 1985. This facility transmitted modulated 76 Hz signals for approximately 8500 hours (96 percent of the available time) and 6900 hours (79 percent of the available time) during 1988 and 1989, respectively. The approximately 4-21 percent of nonoperational time represented scheduled weekly maintenance periods and unscheduled repairs or testing. The north-south and east-west antenna elements were operated simultaneously at 300 amperes for nearly all of the transmission time.

The NRTF-Republic was intermittently operated at less than full power over the period March 1985 through October 1989. This facility became fully operational on 7 October 1989. A more detailed operational history of this transmitter and its counterpart in Wisconsin has been summarized in Reference 2.

In 1988, the NRTF-Republic was operated for about 1000 hours (about 12 percent of the total available time) with north-south and east-west elements separately energized. The operational time was evenly split between the north-south and both east-west antenna elements. The elements were intermittently energized at a 15-ampere current from January through June 1988 and at a 75-ampere current for the remainder of the year. About 41 percent of the total operational time was at 15 amperes, while 59 percent of the operational time was at 75-ampere.

During the first four months of 1989 the NRTF-Republic was intermittently energized at 75 amperes of current with both antenna elements operated separately. Subsequently, the transmitter was operated at 150 amperes with both elements simultaneously energized at modulated and unmodulated frequencies centered at 44 Hz and 76 Hz. Overall, the transmitter was operated during 1989: for about 5100 hours (58 percent of the available time).

3.2 EM FIELD MEASUREMENTS

ELF EM intensities at study sites have been measured annually since 1983 in order to document major changes and also to characterize the temporal variability of fields. During the months of August through October of 1988 and 1989, measurements of 76 Hz EM fields were made at all active Wisconsin and Michigan study sites; 60 Hz intensities were measured whenever possible.

In Wisconsin, slime mold and wetland studies concluded data collection during 1987; therefore, EM measurements during 1988 and 1989 were confined to bird study transects. In addition to historical sites, one treatment and one control transect were extensively characterized during 1988 in order to document the EM variability across the study areas. EM field intensities were measured along the length of both transects and also across the width of the treatment transect. In 1989, intensities were characterized along the length of the remaining four treatment transects.

In Michigan, 1988 EM field measurements were made during 75-ampere operation of the NRTF-Republic; both 76 Hz (unmodulated) and 60 Hz EM fields were measured. The 76 Hz EM intensities at study sites were as anticipated. Unanticipated increases in 60 Hz field intensities at study sites near the north-south antenna element were attributed to increased currents in a transmission line west and parallel to the north-south antenna element. Except for two measurement points at upland flora and soil microflora sites, all 1987 measurement points in Michigan were remeasured in 1988. Nine new measurement points were added to clarify the EM exposures to biota in three studies.

During 1989, EM measurements were made during 150-ampere energization of the NRTF-Republic; both 76 Hz (modulated and unmodulated) and 60 Hz field intensities were recorded. All EM field intensities were as anticipated. With energization at full operational current, EM ratios used for site pairings were recalculated. Two aquatic study elements were relocated to improve their ratios. As initially planned, EM exposures at treatment sites are at least an order of magnitude larger that those at control sites. All 1988 measurement points were remeasured in 1989. New measurement points (24) were added to more accurately characterize the spatial variability of EM fields for four studies.

3.3 OTHER SUPPORT ACTIVITIES

In addition to characterizing transmitter operations and making annual EM measurements, IITRI provided a number of engineering services in response to the unique problems encountered by individual studies. During 1989, special attention was given to the characterization and reduction of EM exposures to study organisms in laboratory environments. Support for characterization of electric field exposures in buried culture chambers also continued during 1989.

EM field measurements were conducted in the laboratories of two studies whose protocols require removal of study organisms from their ambient EM environment for laboratory measurements. At the small vertebrate laboratory, measures were taken to reduce the 60 Hz air electric field by shielding and grounding. Magnetic field exposures during metabolic measurements were reduced with Mumetal shields. At the native bee laboratory, Faraday cages were conconstructed and installed at principal work and holding areas to reduce 60 Hz electric field exposures to the bees.

Soil amoeba studies employ culture chambers that isolate the amoebae from the surrounding soil. Because of the mismatch between the conductivity of the soil and culture media, IITRI-designed control circuitry has been used to match voltages and currents supplied to the culture from collecting electrodes to similar parameters present in the soil.

The intensity of both 76 Hz and 60 Hz earth electric fields varies with seasonal changes in soil conductivity. Therefore, measurement of EM fields once a year may not adequately represent the electric field exposure of the frequently subcultured amoebae. During 1988, IITRI installed microprocessor-controlled data loggers at amoeba study sites. The loggers recorded the earth electric field, as well as electrical parameters within the chamber. At the end of the season, the electrical parameters were used to calculate the electric field and current density within the chamber for the term of the experiment. Earth electric field data were also collected throughout the winter, in order to determine the seasonal variability of this aspect. In 1989, control programs for the data loggers were modified to accommodate a new operating pattern for the NRTF-Republic. Hardware modifications were also made, including the addition of two temperature transducers at each site.

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APPENDIX A

ECOLOGICAL MONITORING PROGRAM:
LIST OF PUBLICATIONS/PRESENTATIONS,
1982–1989

ECOLOGICAL MONITORING PROGRAM: LIST OF PUBLICATIONS/PRESENTATIONS, 1982–1989

<u>**Upland Flora (Michigan Technological University)**</u>

1. Holmes, J. J.; Reed, D. D. Competition indices for mixed species northern hardwoods. Forest Science. (Submitted for publication.)

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Soil Amoebae (Michigan State University)

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2. Band, R. N. Identification of species and strains of *Naegleria* by analysis of restriction fragment length polymorphisms of plasmid and mitochondrial DNA, a simple diagnostic technique. Presented at the International Conference on Biology and Pathogenicity of Free Living Amoebae, Brussels, 1989.

3. Band, R. N. Drought effects annual population size fluctuations and genetic diversity of soil amoebae. Presented at the International Conference on Biology and Pathogenicity of Free Living Amoebae, Brussels, 1989.

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2. Anonymous. Phenology of *Lumbricus rubellus* and *Aporrectodea* spp. (Lumbricidae) in northern Michigan forests. (In preparation.)

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<u>Native Bees (Michigan State University)</u>

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3. Scott, V. L. Nesting biology of *Hylaeus ellipticus* (Kirby) (Cooetidae: Apoidea) in northern Michigan. M.S. Thesis, Department of Entomology, Michigan State University, East Lansing, Michigan, 1989.

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<u>Small Mammals and Nesting Birds (Michigan State University)</u>

1. Beaver, D. L. Breeding biology of tree swallows in the Upper Peninsula of Michigan. Presented at the Annual Meeting of the Michigan Audubon Society, Lansing, Michigan, 1988.

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<u>Bird Species and Communities (University of Minnesota-Duluth)</u>

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2. Hanowski, J. M.; Blake, J. G.; Niemi, G. J.; Collins, P. T. Effects of extremely low frequency electromagnetic fields on breeding and migrating bird species and communities. (In preparation.)

3. Hanowski, J. M.; Blake, J. G.; Niemi, G. J. Seasonal bird distribution patterns along habitat edges in northern Wisconsin and Michigan. (In preparation.)

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10. Hanowski, J. M.; Niemi, G. J. Assessing the effects of an extremely low frequency (ELF) antenna system on bird species and communities in northern Wisconsin and Michigan. Presented at the Lake Superior Biological Conference, Duluth, Minnesota, 1987.

11. Hanowski, J. M.; Niemi, G. J. Statistical perspectives and experimental design in bird censusing. Presented to the American Ornithological Union, San Francisco, California, 1987.

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<u>Wetland Flora (University of Wisconsin-Milwaukee)</u>

1. Hoyst, M. Nitrogen-fixation in *Almus* (tag alder). M.S. thesis, Department of Botany, University of Wisconsin, Milwaukee, Wisconsin, 1988.

2. Guntenspergen, G.; Keough, J. Northern peatlands. Presented to the U.S. Army Corps of Engineers, Waterway Experiment Station, Vicksburg, Tennessee, 1987.

3. Stearns, F.; Keough, J.; Guntenspergen, G. Effects of 76 Hz fields on peatland ecosystems in Wisconsin. Presented to the Eighth Annual Meeting of the Bioelectromagnetics Society, Madison, Wisconsin, 1986.

4. Keough, J.; Stearns, F. Variation in vegetation and water quality in northern Wisconsin bogs. Presented to the NSF Bog Project--Third Group Meeting, Minneapolis, Minnesota, 1984.

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Aquatic Biota—Periphyton (Michigan State University)

1. Molloy, J.: Oemke, M. P.; Burton, T. M. Feeding activity of grazers on periphyton in the Ford River, Michigan. North American Benthological Society, (Submitted for publication.)

2. Burton, T. M.; Oemke, M. P. Annual patterns for the benthic diatom community in the Ford River in Michigan. Presented to the American Society of Limnology and Oceanography, Madison, Wisconsin, 1987.

3. Cornelius, D. M.; Burton, T. M. Studies of *Ophiogomphus colubrinus* in the Ford River in Michigan. Presented to the American Benthological Society, Orono, Maine, 1987.

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10. Stout, R. N. Secondary compounds and litter decomposition in streams. Presented to the Department of Botany, Michigan State University, East Lansing, Michigan, 1987.

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<u>Aquatic Biota—Fish (Michigan State University)</u>

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2. Marod, S. M.; Whelan, G. E. Brook trout movement due to thermal stress in the Ford River, Dickinson County, Michigan. Presented at the Michigan Academy of Science, 1989.

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8. Whelan, G. E.; Gesl, D.; Taylor, W. W. Movements of brook trout, *Salvelinus fontinalus*, in a seasonally variable stream. Presented at the 47th Midwest Fish and Wildlife Conference, Grand Rapids, Michigan, 1985.

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12. Muzzal, P. M. Abundance and distribution of *Salminacola edwardii* on brook trout, *Salvelinus fontinalus*, in four Michigan lotic environments. Presented to the 35th Annual Midwest Conference of Parasitologists, Normal, Illinois, 1983.

Program Management--Engineering Support (IIT Research Institute)

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2. Zapotosky, J. E. Monitoring for Bioelectromagnetic Effects from the ELF Communications System. Presented to the Illinois Association of Environmental Professionals, Chicago, Illinois, 1990.

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4. Zapotosky, J. E. *In-Situ* Monitoring for Bioelectromagnetic Effects from the ELF Communications System. Presented to the Bioelectromagnetics Society, San Antonio, Texas, 1990.

5. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1988 Progress. IIT Research Institute, Technical Report E6620-1, 74 pp.; plus appendixes, 1989.

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Annual Progress (IIT Research Institute/Subcontractors)

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2. Ecological Monitoring Program, ELF Communications System: 1990 Technical Symposium. IIT Research Institute, Houghton, Michigan, 1990.

3. Compilation of 1988 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06595-6, Vol. 1, 572 pp.; Vol. 2, 351 pp.; Vol. 3, 419 pp., 1989.

4. Ecological Monitoring Program, ELF Communications System: 1989 Technical Symposium. IIT Research Institute, Cable, Wisconsin, 1989.

5. Compilation of 1987 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06595-2, Vol. 1, 706 pp.; Vol. 2, 385 pp.; Vol. 3, 491 pp, 1988.

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7. Compilation of 1986 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-38, Vol. 1, 445 pp.; Vol. 2, 343 pp.; Vol. 3, 418 pp, 1987.

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11. Compilation of 1984 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-17, Vol. 1, 528 pp.; Vol. 2, 578 pp., 1985.

12. Ecological Monitoring Program, ELF Communications System: 1985 Technical Workshop, IIT Research Institute, Cable, Wisconsin, 1985.

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14. Ecological Monitoring Program, ELF Communications System: 1983-1984 Workshop, IIT Research Institute, Roscommon, Wisconsin, 1984.

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APPENDIX B

ECOLOGICAL MONITORING PROGRAM: FY 1989 RESOURCES

ECOLOGICAL MONITORING PROGRAM: FY 1989 RESOURCES

The Navy has been committed to a program of long-term ecological monitoring since the ELF Communications System site selection process was initiated. The Ecological Monitoring Program is identified separately from other environmental protection work for future year budgeting purposes; therefore, continuity of the program is anticipated, presuming continued Congressional approval and funding of the ELF Communications System.

During 1989, monitoring studies were conducted under eight subcontracting agreements between IITRI and study teams from three universities (see Table B-1). IITRI provides engineering support and overall program management. Each study team is headed by a principal investigator with academic training to the doctoral level. Most of the staff also have advanced degrees, with expertise and publications in the areas under study. During 1989, the Ecological Monitoring Program consisted of more than 100 people expending a total of about 86,000 staff hours.

TABLE B-1. ECOLOGICAL MONITORING PROGRAM: FY 1989

Study	Subcontractor	Principal Investigator(s) (Total Staff)	Professional and Staff Hours 1989
Upland Flora	Department of Forestry Michigan Technological University	G. D. Mroz, Ph.D. (18 persons)	15,370
Soil Microflora	Department of Forestry Michigan Technological University	J. N. Bruhn, Ph.D. (7 persons)	5,209
Soil Amoebae	Department of Zoology Michigan State University	R. N. Band, Ph.D. (6 persons)	5,298
Soil Arthropods and Earthworms	Department of Zoology Michigan State University	R. J. Snider, Ph.D. R. M. Snider, Ph.D. (15 persons)	15,325
Native Bees	Department of Entomology Michigan State University	K. Strickler, Ph.D. M. Scriber, Ph.D. (10 persons)	7,282
Small Mammals and Nesting Birds	Department of Zoology Michigan State University	D. L. Beaver, Ph.D. (10 persons)	11,164
Bird Species and Communities	Natural Resources Institute University of Minnesota-Duluth	G. J. Niemi, Ph.D. J. M. Hanowski (9 persons)	6,589
Aquatic Biota	Departments of Zoology, Entomology, Fisheries and Wildlife Michigan State University	T. M. Burton, Ph.D. R. J. Stout, Ph.D. W. W. Taylor, Ph.D. (15 persons)	14,982
Program Integration and Engineering Support	Electromagnetics and Electronics Department IIT Research Institute	J. E. Zapotosky, Ph.D. (4 persons)	5,200
		TOTAL	**86,419**